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UPPER STAGE ALTERNATIVES FOR THE SHUTTLE ERA

A NASA/DOD REPORT TO CONGRESS

October 1981

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Honorable Don Fuqua
Chairman
House Committee on Science
and Technology
Washington, D.C. 20515

Dear Mr. Fuqua:

The attached report on Space Shuttle Upper Stages was prepared at the request of your committee during the past spring. The study was carried out jointly by the NASA and DOD and has been reviewed and approved by both organizations.

The report summarizes the status and general characteristics of upper stages now in use or in development, as well as new vehicle possibilities examined during the study. It then discusses upper stage requirements for both civil and DOD missions, categorized generally into near-term (early and mid-1980's), mid-term (late 1980's to mid-1990's) and far-term (late 1990's and beyond). Finally, it examines the technical, schedule and cost impact of alternative ways in which these requirements could be met, and reaches a number of conclusions and recommendations.

Although it is briefly mentioned in the introductory summary, we would like to emphasize that the study clearly illustrates that whenever possible approved satellite programs are designed to have their requirements for launch fall within the capabilities of approved or existing launch vehicles. This practice obviously provides the maximum probability of total system compatibility and reduces the probability of the need for weight saving design changes, reductions in program scope and schedule delays. As a result, however, any advance in launch capability must be based on the anticipated needs of programs not yet approved rather than the firm needs of programs under way. The study, therefore, focused considerable attention on the program requirements anticipated for the late 1980's and early 1990's since these will be based on the launch vehicle decisions and commitments which lie ahead. If we fail to move forward in launch capability, we will severely restrict an important opportunity for flexibility in providing for the advance of spacecraft capability.

The study, therefore, concluded that the Inertial Upper Stage, now in development by the DOD, should be continued to support vital national security and civil missions; and that NASA should undertake the adaptation of the Centaur to be used in the Shuttle to support the near-term Galileo mission and the projected mid-term high energy requirements of NASA, DOD and commercial users. The combined inventory of the two vehicles will adequately accommodate immediate needs and will provide satellite programs an adequate performance margin to proceed with confidence in the development of advanced, more capable systems for the late 1980's and early 1990's.

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One further point should be emphasized. The frame of reference for this study was the President's FY 1982 Budget, as amended in March. Subsequent changes to the National Space Programs may, of course, effect the requirements on which the conclusions reflected in the attachment were based.

We are pleased to submit this joint study report on Shuttle Upper Stages.

Sincerely,

Hans Mark
HANS MARK
Deputy Administrator, National
Aeronautics and Space Administration

VERNE ORR
Secretary of the Air Force

1 Attachment
Upper Stage Study

cc: Honorable Larry Winn, Jr.

Similar letters of transmittal for the report, Upper Stage Alternatives for the Shuttle Era, were sent to:

Honorable Don Fuqua
Chairman
House Committee on Science
and Technology
Washington, D.C. 20515

Honorable Jamie L. Whitten
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Upper Stage Alternatives For The Shuttle Era

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1.0

SUMMARY

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1.0 EXECUTIVE SUMMARY

1.1 INTRODUCTION

The United States Congress, after reviewing the NASA FY 1982 budget request to develop a Centaur derivative to support the planetary exploration program, directed that NASA and the DOD conduct a joint study to determine the nation's upper stage requirements and to define the most appropriate program for meeting these needs. NASA was also directed to reevaluate the sole source Centaur procurement decision; this action will be handled by a separate NASA report to the Congress.

The Space Transportation System (STS) is made up of several major elements. The Space Shuttle is the key element and provides transportation for payloads from earth to low earth orbit. Upper stages are required for payloads which must go to higher altitude orbits or escape the earth and enter interplanetary trajectories. These stages are of different sizes to accommodate the range of payload needs. Small, spin-stabilized, upper stages are being commercially developed to place payloads of 2,750 and 4,400 pounds in geosynchronous transfer orbits. Payload "Kickstages" then place spacecraft of 1,400 to 2,200 pounds into geosynchronous orbits. This report investigates the larger, more sophisticated three-axis stabilized upper stages. These include the Air Force's Inertial Upper Stage (IUS), capable of 5,000 pounds to geosynchronous, now nearing completion of development, and the NASA wide-body Centaur (13,000 pounds to geosynchronous) which is a modification of an existing expendable launch vehicle stage.

An STS configured Transtage (8,000 pounds to geosynchronous), which is representative of the storable propellant systems, and a Shuttle-optimized Interim Orbital Transfer Vehicle (IOTV), a cryogenic propellant stage somewhat larger than the Centaur, were also evaluated. The STS Transtage configurations differ depending on mission unique requirements ie... 8,000 pounds to geosynchronous orbit and a configuration with a Delta 3920 second stage and a solid kickstage motor as a third stage for planetary missions. The major constraint on the IOTV was for a new stage, ie... new development, at lowest cost to meet requirements in the late 1980's and early 1990's. By definition, such a stage would satisfy all technical requirements, however being a new stage, higher development complexity, schedule and cost risk will exist.

Both NASA and DOD examined their current and projected mission requirements and evaluated each of the upper stages (IUS, Centaur, Transtage, IOTV) against those requirements.

The determination of upper stage requirements focused on near-term "firm" requirements: those imposed by currently approved programs; and on "anticipated" requirements: those imposed by major planned program changes and upgrading; and, to a limited extent, on the more distant requirements or program considerations still in the very early conceptual stage. The examination of near-term requirements confirmed that almost without exception, approved programs are based

on the launch vehicle and upper stage capabilities which exist or are in development at the time of program approval. Only where programs encounter exceptional growth or the addition of a new mission requirement do "firm" launch requirements exceed approved capabilities. The requirement to improve launch capability therefore depends upon "anticipated," rather than "firm," program requirements. To a significant extent, therefore, the conclusions and recommendations of the study focus on the limited "firm" requirements which approach or exceed approved upper stage capabilities and on the "anticipated" requirements based on near-term planned program changes and upgrading. Only in this way is it possible to provide a launch capability which will allow those program changes to be made with confidence that their launch requirements will be met.

1.2 REQUIREMENTS

NASA and defense requirements differ in signficant ways, and therefore have been analyzed and discussed separately. NASA upper stage requirements encompass both planetary exploration and earth orbiting (civil government and commercial) missions.

NASA planetary requirements are directly related to upper stage performance; the greater the upper stage performance, the greater the scientific/exploration benefits that can be established and accomplished. The design of interplanetary missions usually begins with the use of "optimum" trajectories which will permit reaching the target destination(s) at specified times and locations with minimum additional spacecraft propulsion capability. Once the upper stage capability and availability are factored in, trajectory adjustments are made to "recapture" the mission. Essentially, the development of the final mission requirements is an iterative process whereby adjustments often result in constraints or degradations to the original mission design expressed in terms of (1) added trip time to the planets, (2) more launches, i.e., payload split into two or more parts, (3) deferred launch dates, (4) use of low-energy, gravity-assisted trajectories based on specific launch opportunities, (5) addition of high energy propulsion systems in the spacecraft itself which complicates design and raises cost, and/or (6) reduction in mission objectives. Final mission requirements are a compromise relative to upper stage capability, payload weight, mission time, mission reliability, qualitative and quantitative accomplishment of mission objectives and overall mission cost or available funding.

NASA advanced study results over the past several years relative to large space structures show that materials technology makes such payloads as large space platforms and antennas now practical in earth orbit for the late 1980's. Such payloads, because of size and fragility of their structure will require upper stage performance with low thrust capability to prevent structural damage from excessive acceleration.

NASA is also responsible for enhancing this nation's technology in order for us to compete more effectively in international markets. Commercial communications spacecraft are an important factor in this competition. The evolution of commercial spacecraft since the early 1960's has been analyzed. The historical trend showed that starting around 1975 spacecraft weight began to stabilize in order to maintain dual capatibility with the STS and expendable launch vehicles. This has required users to limit spacecraft weight and size and increase number of spacecraft, support development of other carrier systems, develop more complex equipment to fit within weight and size limits, etc.

Defense missions place a wide range of demands upon all elements of space transportation, including upper stages. These requirements go well beyond the need for a significant amount of energy for payload injection and consider a wide range of operational factors important to maximizing the operational availability of critical defense spacecraft missions. These demands can be expected to increase over time along with demands for increased payload weight lifting capability.

Currently approved and funded DOD operational space programs require 5,000 pounds placed in a geosynchronous orbit (that is, an orbit such that the spacecraft stays at a point over the equator). Projections of firm requirements for operational defense programs indicate this requirement will grow to 5,500 pounds in the late 1980's. Furthermore, these operational DOD programs would like to have a capability of 5,500 pounds in 1987, growing to 6,200 pounds in 1988. Payload weight in final orbit is the most important discriminator between stages; limited weight capability can force mission limitations or increase spacecraft cost to implement weight reduction programs.

A number of existing operational defense space programs project significant payload weight increases beginning in 1990 as a new sequence of block change spacecraft become operational. For those programs which do not grow dramatically, the IUS could remain as the primary launch vehicle. However, for programs whose weight in geosynchronous orbit grows into the 8,000-10,000 pound range, a significantly more capable upper stage is likely to be required. A new upper stage based either on cryogenic or storable propellants would be suitable for missions in this weight class.

An assessment of advanced defense mission concepts (all of which would represent new program starts) shows that in the late 1990's and in the early twenty-first century, that additional significant increases in payload weight will be needed and that a number of different high energy orbits will come into operational use. Since the Shuttle will likely still be the primary vehicle for launching such systems, then the performance limitations will be determined

primarily by the upper stage selected. Consequently, the Shuttle throw weight limits -- combined with dramatic increases in mission requirements -- will ultimately result in the need for the high-efficiency, high-energy levels provided only by cryogenic liquid propellant stages.

1.3 ASSESSMENT SUMMARY

An assessment of the overall NASA requirements shows that a high energy stage is needed to fulfill projected NASA and commercial needs. Assessment of upper stage program options reveals that the decision should be based on schedule and performance rather than life cycle cost (since cost is not a major discriminator). The long range cost analysis results showed that the variance between options was small and within the error inherent in the numbers used in the analysis. The near term cost analysis as related only to planetary missions showed that the cost variations between the options, with the exception of the IOTV options, were small.

An assessment of upper stage candidates against the DOD requirements can be summarized as follows: The Inertial Upper Stage (IUS) can meet nearly all the firm defense needs, and the IUS can be easily modified to "capture" the small region of missions not within its basic design capability of 5,000 pounds to geosynchronous orbit. The Transtage (or other similar storable propellant systems) can satisfy all the firm defense needs, but can only capture a small portion of the projected growth. Shuttle payload limits (65,000 pounds) will limit both the IUS and Transtage growth such that these systems can never capture a significant portion of the projected long term defense needs. The cryogenic propellant stages (Centaur and IOTV) can capture a very large portion of the projected growth, and when combined with the solar electric propulsion system (using two Shuttle flights) could even capture a portion of the large high altitude platform missions.

Consequently, it appears logical to retain the IUS and make necessary incremental performance improvements to meet firm defense needs. There appears to be little benefit to transition to the Transtage, or another storable propellant system, since this approach does not add to current mission capability and does not capture a significant portion of the projected growth. The logical step for defense missions is to supplement the IUS capability with a high performance cryogenic upper stage which will have long term utility.

1.4 JOINT NASA/DOD CONCLUSIONS

The IUS is the only available stage capable of meeting the near term earth-orbiting requirements for DOD and NASA and, with modifications, could satisfy NASA and DOD earth orbiting missions through the 1980s.

The Transtage (or other storable propellant vehicles) could satisfy near term NASA and DOD earth-orbiting requirements from a performance standpoint, but cannot be available in sufficient time to

meet current program schedules. In addition, it is not efficient for NASA planetary missions and falls short of meeting projected long term national security performance requirements.

An IOTV, since it would be optimally designed to meet national requirements, would be the best upper stage to meet the long term performance and operational needs of both NASA and the DOD. However, this approach is not acceptable since the development time required for such a new stage would not allow the NASA near term requirements to be met. In addition, cost and schedule risks would be considerably higher than for the Wide-body Centaur.

The Centaur is the only vehicle capable of meeting near term NASA planetary requirements, particularly the need for a Galileo combined Orbiter/Probe mission on a direct trajectory to Jupiter in 1985. The Centaur will satisfy the future envisioned and proposed NASA planetary missions through the mid-1990's. The Centaur could also be adapted to meet both current and projected NASA and DOD earth-orbiting requirements and its early availability could offer an option for considerable enhancement of DOD mission capabilities.

Development of a cryogenic upper stage will strengthen the United States leadership role in both hydrogen/oxygen engine technology and in payload lift capability. The long range requirements will drive upper stages toward the very high specific impulse performance provided by hydrogen/oxygen cryogenic stages. Proceeding with a cryogenic upper stage will maintain the small engine cryogenic technology lead, maintain a second domestic source of cryogenic expertise, and strengthen the government's long term competitive opportunities. Proceeding with the wide body Centaur will accomplish these ends and provide a significant and timely jump in upper stage performance. This will allow the United States to compete with the Ariane and also maintain our clear preeminence in the important field of cryogenic engine technology.

1.5 RECOMMENDATION

In order to satisfy the national mission requirements of both the DOD and NASA, the Air Force should continue development and production of the IUS and NASA should develop the Centaur.

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2.0

INTRODUCTION

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STUDY
UPPER STAGE ALTERNATIVES FOR
THE SHUTTLE ERA

2.0 INTRODUCTION

The Space Transportation System (STS), is made up of several major elements. The Space Shuttle is the key element and provides transportation for payloads from earth to low earth orbit. However, many missions require transportation to orbits and earth escape trajectories which are not attainable by the Space Shuttle. To accomplish such missions, propulsive stages with the mission payloads attached are carried to low earth orbit by the Space Shuttle and launched from the Space Shuttle. These propulsive stages are called upper stages.

Payload missions requiring upper stages fit into different categories. These categories are defined by mission energy requirements which are characterized by mass to be delivered to a particular orbit, unique trajectory or destination. To best accommodate these varying mission energy requirements, upper stages of different sizes and energy capability are required. Such Upper Stages are planned and under development by NASA, DOD and commercial developers.

The McDonnell Douglas Corporation is developing, as a commercial venture, Spinning Solid Upper Stages, the SSUS-D and SSUS-A, to accommodate future payloads of the energy classes which are currently flown on the expendable Delta and Atlas Centaur launch vehicles. The performance of the SSUS-D and the SSUS-A, respectively, is 2750 pounds and 4400 pounds to a geosynchronous transfer orbit. This is approximately equivalent to 1400 pounds and 2200 pounds in geosynchronous orbit. A multiple mix of SSUS's and other payloads can be flown on a single Shuttle flight.

The Air Force is currently developing a two-stage solid propellant upper stage known as the Inertial Upper Stage (IUS) for accomplishing earth orbital missions requiring more energy than can be provided by the SSUS vehicles. The IUS will be compatible with the Titan III (34D) launch vehicle and the Space Shuttle. The IUS as baselined for use with the Space Shuttle can deliver 5,000 pounds to geosynchronous orbit. The IUS will be used by NASA for launching the Tracking Data Relay Satellite (TDRS) missions and will be used by DOD for various missions.

A third category of missions exists which requires higher energy capability than can be provided by the IUS. Effective unmanned exploration of outer space and other planets requires propulsive capability beyond that offered by the IUS. NASA has approved and planned planetary missions to accomplish these objectives. In addition, the historical growth curve for geosynchronous satellites indicates that a greater capability than 5,000 pounds to geosynchronous orbit should be available to permit spacecraft growth in the late 80's or early 90's. Advanced payload planners are also

currently planning large space structures which will eventually require higher energy upper stages. Europe's Ariane project plans, as of mid-1981, included growth potential to accommodate a payload of 12,000 pounds in geosynchronous transfer orbit (approximately 7,000 pounds to geosynchronous orbit). Later information indicates that their capability for Ariane V could be as high as 8,500 pounds to geosynchronous orbit. The Ariane IV first stage, which is also the first stage for Ariane V, will now have liquid strap-on engines which increases performance by approximately twenty percent.

NASA, currently with letter contracts, has initiated effort to adapt Centaur to the STS in order to meet these current and future requirements.

2.1 PURPOSE/SCOPE

The NASA approach for accomplishing current and predicted future requirements has been questioned by Congress and a joint agency, NASA and DOD, analysis has been performed to determine the basic national requirements and the best national approach (i.e., vehicle or family of vehicles) for satisfying these requirements. In addition to providing the results of the analysis, this report has purposely been structured to provide background information relative to requirements, upper stage configurations and options, study approach, and associated payload and STS data to permit others to derive their own conclusions. Extracts from other documents, analysis results, reports, etc., have been incorporated directly rather than by reference to permit ready assimilation of the report.

2.2 SCOPE LIMITATIONS

The purpose of the analysis was to determine the best national upper stage approach to meet the current and projected national requirements. The effort was not intended to be a precise budget analysis whereby cost data utilized or resulting from the study would replace budget information submitted through proper channels in and from NASA and DOD. However, the cost data utilized in the study is the best information currently available and was derived from valid sources with changes in format and terminology to allow accurate comparative analysis to be performed among options. Again, the report is not intended to be a budget or funding requirements document for NASA or DOD and should not be used for that purpose.

The SSUS programs, although acknowledged during performance of the analysis, were not a major point of concern in that higher performance vehicles are being questioned. Therefore, the scope is limited relative to these projects and the report only addresses them for completeness.

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3.0

BACKGROUND

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3.0 BACKGROUND

The question, "Which are the most appropriate upper stages to best meet the national needs", has been studied and restudied extensively for the past 10 years. An in-depth, well prepared, summary scenario of early study results, of which many of the basic facts are still valid today, exists in the documented "Hearings Before the Subcommittee on Manned Space Flight of the Committee on Science and Aeronautics, U.S. House of Representatives, Nineth-Third Congress," published under title of Space Tug-1973.

Since the Congressional hearings in 1973, many decisions were made by NASA and DOD, with Congressional oversight, relative to upper stage programs. These decisions, arrived at mutually as partners for use and in development of the STS, were made based on best information, i.e., technical and budgetary existing at the time and with concern for national interest and policy.

3.1 HISTORY

During the fall of 1975, NASA and DOD agreed that DOD would develop an Interim Upper Stage for national use and that NASA would plan for development of a Space Tug, i.e... high energy stage, to be initiated in the early eighties. The initiation of the Interim Upper Stage program began with the Air Force Validation Phase Contract with the Boeing Company in September 1976. A contract was awarded in 1978 for the development phase and the vehicle was then designated the Inertial Upper Stage. NASA participated in the selection process and provided funds to the Air Force, under a mutual agreement, for NASA-unique systems and stages. The Air Force was to develop a two-stage vehicle for use by DOD and NASA with an STS capability of 5,000 pounds to geosynchronous orbit. The vehicle was also to be used by the Air Force with the Titan III (34D) for the Shuttle transition period and STS backup. The unique NASA vehicles to be developed by the Air Force with NASA funds were to be high energy twin and three stage IUS's for accomplishing planetary missions.

Original planning provided for a Galileo mission in early 1982 and an International Solar Polar Mission (ISPM) in early 1983. In late 1979 it became questionable whether the Space Shuttle/IUS could support the early 1982 Galileo launch and at that time NASA reviewed several alternative approaches to meeting the mission objectives. The most viable alternative at that time was to split the Galileo Orbiter/Probe combined payload into two separate Shuttle/IUS flights and slip the launches into early 1984, while maintaining the ISPM launch in 1983. This alternative remained viable when the Air Force decided in December 1979, following a comprehensive evaluation of IUS alternatives, to continue the IUS development program.

After NASA's announcement to Congress in November 1979 of plans to redirect the Galileo program, Congressional requests were made to: first, conduct a reassessment of the Galileo and ISPM to again evaluate the use of the Centaur liquid upper stage for these missions in lieu of the IUS and, second, examine future upper stage

mission requirements. In response, NASA performed a reassessment of the Galileo and ISPM missions, reevaluated the use of Centaur as an upper stage and examined future upper stage mission requirements and forecasts through the 1985-2000 time frame.

The results of the study were documented in a report, "Study of Upper Stage Alternatives for Space Transportation Systems Mission Operations," dated 3 May 1980. Based on both Air Force and NASA programmatic and budgetary decisions, the upper stage baseline posture for near-term Space Transportation System operations appeared to meet the then currently planned mission requirements and NASA recommended the Galileo mission be flown on two Shuttle/IUS flights in 1984 and the then known (one NASA and one European spacecraft) ISPM mission on two Shuttle/IUS flights in 1985. It was also concluded that, from a technical and operational viewpoint, the Centaur could be modified and integrated with the Space Shuttle and meet the mission performance requirements of Galileo and ISPM (one flight each). However, the orbiter development schedule was intense leading to the first manned orbital flight and it was not the proper time to introduce additional schedule risk with early introduction of the liquid cryogenic Centaur into the Space Shuttle. The cost, at that time, of the Centaur alternative showed an increase over the then existing baseline IUS program. Relative to the review of mission forecasts through the 1985-2000 time frame, the results indicated the need for future upper stages of much greater capability and flexibility than the IUS and that a cryogenic upper stage (an initial version of the Orbital Transfer Vehicle/OTV) should be introduced into the Space Shuttle in the late 1980's. Additional studies were initiated to determine the complexities of integrating the Centaur into the Shuttle.

Congressional responses agreed to the Galileo and ISPM redirection and NASA and the Air Force proceeded with implementation of the plan as the most cost beneficial means of mission execution.

The combination of planetary mission requirements increases, mission delays, and overruns in the basic two-stage IUS development program combined to increase NASA IUS budget requirements by about $100M in FY 81/82. Budget constraints necessitated a slip of the Galileo and ISPM missions from 1984 and 1985 to 1985 and 1986. Slipping the Galileo from 1984 to 1985 increased the energy requirement markedly because of changes in the relative positions of the planets. The only way the IUS could perform the mission would be via an indirect trajectory, Delta-Velocity Earth Gravity Assist (Δ -VEGA) which added considerable mission time (approximately 3 years) and related mission costs (approximately $200M), as well as degraded mission reliability. In response to the situation, NASA (in conjunction with DOD) performed an upper stage alternative stage study and presented the results to the joint NASA/DOD Aeronautics and Astronautics Coordinating Board (AACB) in March 1981. The AACB conclusions were that the Air Force continue the development of the two-stage IUS and that NASA develop a Centaur derivative for the high energy planetary missions. With these conclusions, NASA directed the Air Force to discontinue development of the planetary versions of the IUS, notified Congress of NASA's intent to initiate the Centaur STS program and proceeded to initiate letter contracts required to protect the mission launch schedules.

3.2 CURRENT SITUATION

Although Congressional concurrence exists for the limited liability letter contracts for initiation of the Centaur STS program, Congressional concern was expressed relative to the nation's basic upper stage mission requirements having been adequately defined and whether or not the Centaur is the appropriate approach for satisfying the national requirements. To this end, another joint NASA/DOD Alternative Upper Stage Study was requested. This report provides the results of that study.

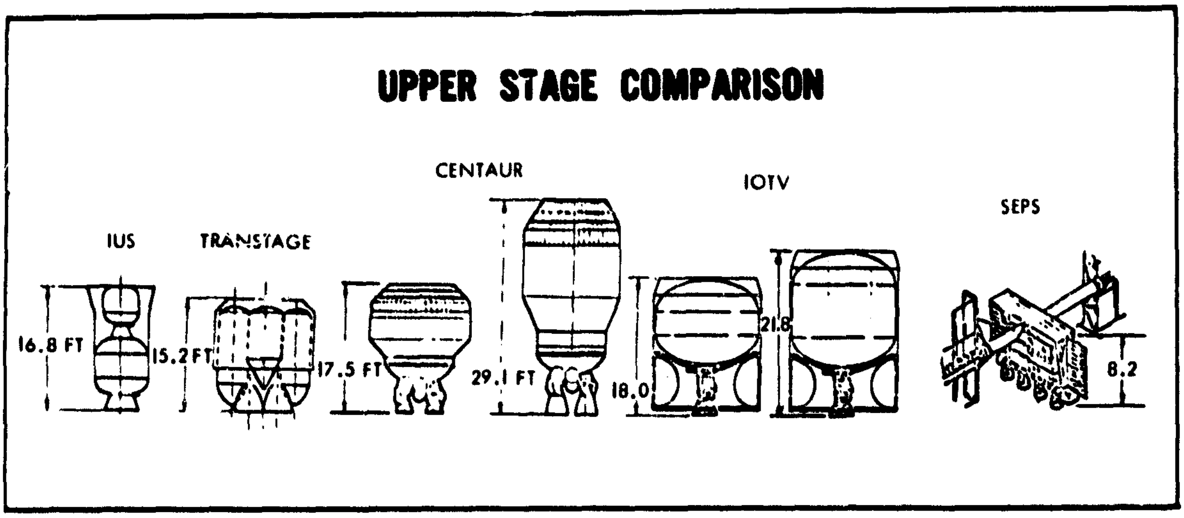
3.3 UPPER STAGE OPTIONS/STAGE DESCRIPTIONS

NASA and the Air Force, as the DOD representative, have performed a comprehensive and in-depth analysis of upper stage program options, including expendable launch vehicle/upper stage combinations.

The Upper Stage vehicles receiving the major effort as viable options were the IUS, Centaur, Transtage and several versions of a cryogenic Interim Orbital Transfer Vehicle. A brief description of these vehicles and associated systems is provided here for technical reference. As the use of the Solar Electric Propulsion Stage (SEPS) with all vehicles was considered, a brief description of SEPS is also included in Section 3.3.5. A study was also performed relative to use of a small storable stage with the Centaur STS. This combination provides for utilization of the best features of both storable and cryogenic stages. Different ways to implement the major system concepts (cryogenic, solid, solar electric and/or storable propellant stages) were studied and discussed. Since the stages used were the best performers of the classes of vehicles, the basic report conclusions would not be changed by including a greater number of stages or concepts in the assessment. The following describes the candidate upper stages used for detailed analysis for this study.

Figure 3.3-1 provides a pictorial comparison of the prime upper stage options considered for the STS.

FIGURE 3.3-I



3.3.1 IUS STS

The basic IUS is a two-stage solid propellant vehicle being developed by the Air Force and planned for DOD, NASA and civil use. It will be used both with the Space Shuttle (first flight late 1982) and on the Titan launch vehicle (first flight mid-1982). The reference STS mission was for 5,000 pounds into geosynchronous orbit.

The IUS has redundant critical components such as navigation and guidance avionics, reaction control systems and backup electrical power supplies which will provide a calculated vehicle reliability of better than 98 percent. It uses two solid-propellant motors, a large first stage motor containing 21,400 pounds of propellant and a smaller second stage motor with 6,000 pounds. A second stage motor extendable exit cone to provide increased performance is standard with the STS configuration and optional for Titan. The IUS Twin-Stage was also reviewed again as an option for performance of planetary missions. The IUS Twin-Stage utilizes two 21,400 pound motors.

3.3.2 CENTAUR STS DESCRIPTION

The Centaur STS is a wide-body derivative of the upper stage of the expendable launch vehicle, the Atlas Centaur (AC). The Centaur STS is taking maximum advantage of current Centaur design, with minimum changes, to accomplish required performance parameters and compatibility with other existing elements of the STS. Only mandatory functional systems, or safety required changes are being considered in order to preserve already demonstrated high reliability and to provide the lowest possible development cost and schedule risk leading to the Galileo mission to Jupiter in April 1985. The Centaur STS will be capable of placing approximately 13,000 pounds into geosynchronous orbits.

With future requirements under consideration, the multiburn capability inherent in the reference vehicle configuration is being preserved in the STS version. The current inherent adaptability for engine low thrust operation will also be preserved. The wide-body inherent design will provide the capability to shorten the stage, if required later, to provide short, high energy stages for long payloads (up to 42 feet) within the Orbiter cargo bay constraints. Centaur airborne support equipment (ASE) is being developed for support of the Centaur STS while in the Shuttle cargo bay and will be reusable with minimum refurbishment between flights. Dependence on orbiter systems and interfaces with the Orbiter will be minimal while maintaining compatability with basic safety requirements. Utilization of existing facilities and ground support equipment (GSE) at the manufacturing plant and the launch site to the maximum extent, is part of the basic plan.

3.3.3 STS TRANSTAGE DESCRIPTION

The Transtage has been flown on the Air Force Titan vehicle since the early 60's. The plan, as it existed with the start of the IUS program in 1976, was to phase out the Transtage with the evolution of the Titan III (34D) and the IUS. In the early 70's and as explicitly discussed in the Hearings before the Subcommittee on Manned Space

Flight of the Committee on Science and Astronautics, U.S. House of Representatives in September 1973 and documented, reference Space Tug-1973, the Transtage and advanced versions have previously been considered for use as an STS upper stage element.

With the advent of the IUS contract in 1976, the Transtage was no longer considered as a candidate for the STS upper stage. However, with the announcement by NASA to cancel the three stage IUS program, the Martin Marietta Company provided the Air Force, and later NASA, with data relative to advanced versions of the Transtage family for consideration for utilization with the Titan III (34D) and the STS. These stages would be growth versions of the TIIIC Transtage. To insure that there were not better Transtage options available, NASA expanded the family, for analysis purposes, by adding a kickstage to the configurations provided. A dual standard Transtage configuration was also reviewed again for performance.

3.3.4 INTERIM ORBITAL TRANSFER VEHICLES (IOTV) DESCRIPTION

Many studies have taken place over the past decade relative to Orbital Transfer Vehicles (OTV's) and/or Interim Orbital Transfer Vehicles (IOTV's). Some of these studies were performed by NASA in-house, some by contractors to NASA and DOD, and many were performed by various companies with their own funds. As would be expected, the capability of the various theoretical vehicles varied considerably depending on basic assumptions such as mission models, timeframe required, manned requirements or growth capability to manned requirements, etc.... For the purpose of this study, a version as provided by MSFC was utilized but other configurations were included in summary fashion which would require more complex development with associated cost and schedule considerations.

The version selected as an option is an IOTV configuration, not optimum as far as maximum performance, but with performance close to that which is foreseen to be required through the early 90's. Growth or adaptability to a larger IOTV size however, was a basic assumption. The major constraint was for a new stage, i.e., new development, at lowest cost to meet limited requirements in the late 80's and early 90's. More accommodating new vehicles at higher cost could also be made available during the addressed time frame should new/practical requirements become visible and provide the demand.

3.3.5 SOLAR ELECTRIC PROPULSION STAGE (SEPS) DESCRIPTION

Similar to a kickstage, SEPS will be launched on the Shuttle and boosted higher by a Shuttle upper stage. The primary advantage of SEPS over conventional chemical vehicles is its inherent ability to provide a large velocity capability due to the very high specific impulse and thereby achieve very high energy missions that cannot be accomplished otherwise.

The distinguishing characteristic of the SEPS is its propulsive method. Solar radiation is collected by large solar arrays and converted into the kinetic energy of the exhaust beam. Electric power conditioners produce the voltages required to operate the thrusters. Thrust results from the electrostatic expulsion of mercury ions. Electrons from a neutralizer are injected into the main beam path to prevent a charge buildup on the vehicle. For most missions a specific impulse of 3000 seconds gives a good compromise between thrust level and propellant utilization. Specific impulse is a measure of propulsion efficiency. SEPS offers a specific impulse on the order of seven to ten times the best achievable from chemical propulsion systems.

The availability of the SEPS stage for flight is a function of the program approval date and the available funding. Program definition studies (Phase B) have been completed and availability would be approximately 45 months after initiation of a development program.

SECTION

4.0

REQUIREMENTS

4.0 REQUIREMENTS

4.1 NASA UPPER STAGE REQUIREMENTS

4.1.1 SHUTTLE CAPABILITIES/CONSTRAINTS

The Space Shuttle is the key element in the STS. Payloads and carrier vehicles such as upper stages are constrained to the weight, volume and environment provided by the Shuttle element. Safety requirements and operational constraints of the Shuttle system must also be taken into consideration when calculating usable upper stage and payload mass. The payload weight of 65,000 pounds to a circular 150 nautical mile orbit with launch due east from Kennedy Space Center is the performance reference used for most of this study. Other payload weights and launch inclinations have been discusseu by the study team as related to Upper Stage vehicle and overall STS performance in order to evaluate and understand STS flexibility for future missions. In general, many of these discussion results are not included in the text in order to keep the text from becoming too lengthy. But it is obvious that, with higher payload capability or higher energy stage availability, more mission flexibility will exist in a changing and demanding environment as requirements evolve in later years. Other ramifications were also analyzed such as the ability for upper stage capability growth (i.e., Centaur currently offloading 10,000 pounds of propellants for geosynchronous orbits because of 65,000 Shuttle limitation). As liquid stages can dump propellants during abort/contingency situations they aren't constrained by landing requirements as are solid stages and lift off weight can therefore grow to existing tank capacity without additional future modifications to the upper stage.

The total payload, upper stage and spacecraft, is constrained to 60 feet in length and 15 feet in diameter as provided by the Orbiter cargo bay. Other factors such as orbiter center of gravity limitations affect the placement of the payload in the bay and can impact upper stage designs. Support structure considerations in the cargo bay also vary with stage and payload length requirements. These considerations were treated generically during the study. The length and volume provided by the Orbiter is not a limiting factor for NASA payloads currently under consideration, however, considerable discussion did take place during the analysis relative to length requirements for DOD payloads. This matter is discussed under DOD requirements.

The safety and environmental constraints were addressed in the study to the detail necessary for assurance that each upper stage option would be compatible with Shuttle constraints and that allowances to meet constraints/requirements were provided for in overall cost data.

4.1.2 EARTH ORBITING MISSION REQUIREMENTS

In assessment of large earth orbiting upper stage missions, the Tracking Data Relay Satellite (TDRS) missions are the only currently funded NASA missions. These utilize the full capability of the IUS, i.e., 5,000 pounds into geosynchronous orbit. The first flight of TDRS is now scheduled for December 1982. A total of six TDRS launches are currently planned with a seventh as a possible later requirement.

The search for hard, firm requirements in the commercial community, reveals the fact that spacecraft investors do not plan to spend funds to design and build spacecraft which exceed the delivery capability. The uncertainty in the development of higher performing upper stages for the STS has been and still is influencing user policy relative to planning advanced high performance spacecraft/satellites.

Discussion with INTELSAT, COMSAT, and others* does indicate that commercial payload developers desire spacecraft with weight to geosynchronous orbit requirements which far exceed existing carrier capability. Intelsat VII could require, if an accommodating demonstrated upper stage capability exists, the placing of 9,000 to 12,000 pounds in geosynchronous orbit in the early 1990's. It should be noted that current Intelsats are designed so as to have an integral propulsion capability such that final placement is from a geosynchronous transfer orbit, which allows compatibility with the Ariane launch vehicle. Intelsat VI has a design requirement to be compatible with both the Space Shuttle and the Ariane.

TABLE 4.1-1

GEOSYNCHRONOUS ORBIT
COMMERCIAL SPACECRAFT APPLICATIONS/GROWTH

- 0 MID-60'S - 100-200 POUNDS
- 0 LATE 60's - INTELSAT I II - 300-350 POUNDS
- 0 MID-70'S - INTELSAT IV - 1,500 POUNDS
- 0 EARLY 80'S - INTELSAT V - 2,000-2,200 POUNDS
- 0 1986 - INTELSAT VI - 4,000-4,400 POUNDS
- 0 EARLY 90'S - INTELSAT VII - 9,000-12,000 POUNDS*

* PER LETTER FROM INTELSAT

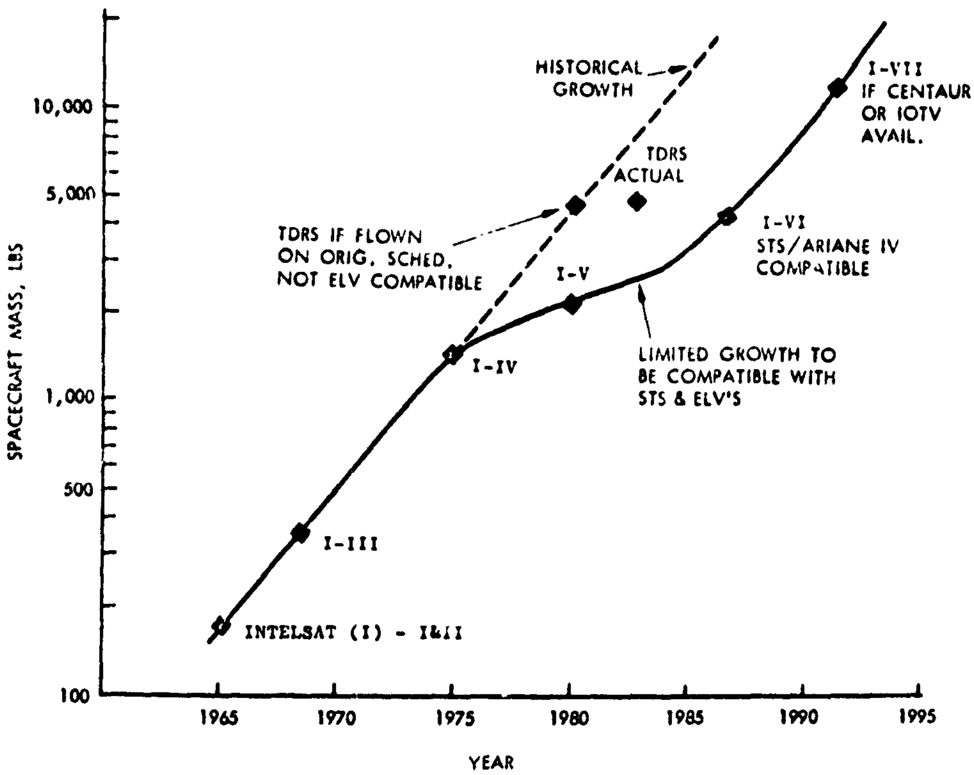
*Letters, Intelsat to NASA, dated 3 August 1981, N.J.M. Chitre to Dr. Hans Mark; COMSAT Satellite Television Corporation to NASA, dated 7 August 1981, L. Keane to Dr. Hans Mark; COMSAT General Corporation to NASA, dated 13 August 1981, B.I. Edelson to Dr. Hans Mark.

Table 4.1-1 and Figure 4.1-1 are a tabulation and graphical presentation of the historical and predicted growth of communications satellites since the launch of the first commercial ventures in the mid-1960's. Analysis of the tabulations clearly shows the trend relative to past and future spacecraft carrier requirements. These trends have in the past pushed the modification of the Atlas Centaur and Delta, to provide increased payload capability. It must also be recognized that growth in weight has been restricted in the late 1970's and 1980's by the need for dual compatibility, i.e., compatible both with STS and available existing ELV's while in addition, the growth of U.S. ELV's has been purposely limited because of phaseout plans.

At this time there are no (other than TDRS) commercial satellite companies planning to use the IUS. This is for several reasons. The cost uncertainties make commercial use/planning difficult. The demonstrated capability that it is a functional part of the STS will not take place until late 1982. Assuming spacecraft development takes four years or more, should a spacecraft developer, at this time decide to fly on the IUS, his flight date would be late 1985 or early 1986. These uncertainties would tend to dictate that he find some other means to satisfy the "user" requirements i.e... continue with smaller highly complex and costly spacecraft and fly more of them or find another carrier vehicle. Intelsat is designing for the Ariane, at least through the Intelsat VI series, but prefers the larger spacecraft approach for long range planning. If the Centaur proceeds through development, Intelsat would probably plan earlier conversion to the higher STS capability.

FIGURE 4.1-1

HISTORICAL/FUTURE GROWTH TRENDS COMMUNICATIONS SATELLITES



The area of spacecraft growth, i.e., physical size versus other ways of meeting increasing demands has received considerable thought and discussion. Increasing size can be relatively low in cost versus the cost to develop smaller, more complex components to fit into limited available dimensions to accomplish a specific task or mission, for example, insertion and placement accuracy and station keeping functions. The trade of increasing spacecraft size, i.e., propellant tanks, for greater placement accuracy may be more economical than designing and procuring complex, highly reliable avionics systems for the launch vehicle and/or spacecraft. But if carrier energy, i.e., launch vehicle/upper stage capability, is limited, then both the upper stage and the spacecraft must take the sophisticated, expensive route of costly avionics systems to achieve final placement accuracy. The reliability, relative to useful life, is also affected. A spacecraft with twice as much propellant as another, other systems being equal, can obviously maneuver and remain stable relative to position longer than one with half the capacity. It also provides flexibility to better accommodate changes in position to maximize services. The trend to larger spacecraft in the future in order to decrease cost, extend life, and expand services can only be accomplished through compatible carrier growth. The cost impact of lack of spacecraft growth, as shown in Figure 4.1-1, in 1975 and extending into the indefinite future is impossible to estimate, The remedy however, is to eliminate as much as possible, carrier requirement restrictions, and permit spacecraft developers to determine competitively spacecraft services, weight and size requirements.

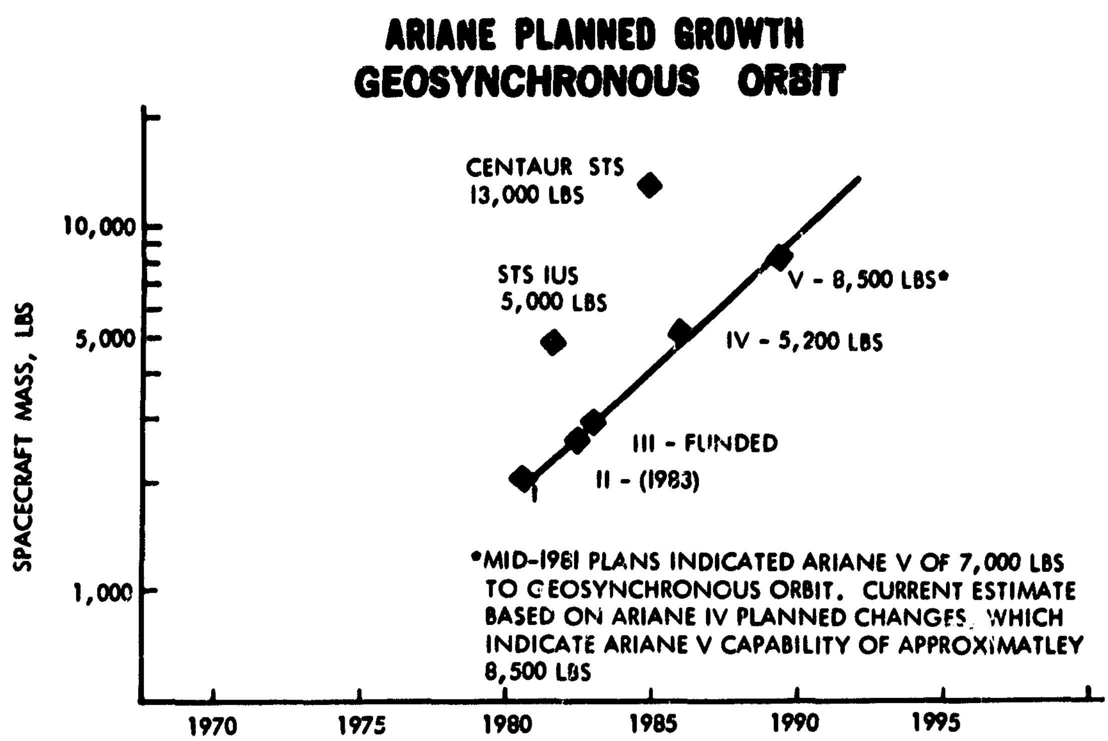
A recent analysis by Battelle, Columbus Laboratories* reveals that the geosynchronous arc appropriate for commercial satellites is becoming crowded, in a radio frequency (RF) sense, and strong competition exists for scarce "slots" (World Administration Radiation Conference-WARC, North-South competition). The demand for geosynchronous transponder capacity is strong (no unleased capacity and a "Futures Market" is taking place). "De Facto" larger satellites are being created by colocating existing satellites in one location (Comstar, ANIK-A) and in some current locations services and users are beginning to coalesce.

*Report, COMMERCIAL USE OF SHUTTLE/CENTAUR Battelle, Columbus Laboratories, dated August 18, 1981.

These platforms will require high energy upper stages for delivery. The Battelle analysis also indicated that commercial spacecraft designers require 4-5 years time between design initiation and flight. As they design to launch vehicle capability, this means that designers of early 1990's spacecraft will use what exists in the mid-1980's relative to upper stage capability. A recent study performed by the AIAA** for The White House, substantiates most of the Battelle study results.

In order to establish a figure of merit on how other launch vehicle developers see the payload growth requirements versus carrier requirements, the Ariane growth plan was examined and is shown in Figure 4.1-2. This curve, i.e., essentially an exponential growth, is significant to consider, especially when it must be recognized that the growth plan requires a considerable investment of funds. The Ariane planned growth curve substantiates U.S. data relative to expected spacecraft requirements in the late 1980's and early 1990's.

FIGURE 4.1-2



**Report; Projection of Non-Federal Demand for Space Transportation Services Through 2000-An AIAA Assessment For The Office Of Science and Technology Policy, The White House; dated 19 January 1981.

NASA advanced study results over the past few years have also projected the need for heavy lift capability. For example, large space structures have been studied in detail. Materials technology makes such payloads now practical for the late 80's. Such payloads require upper stage performance with low thrust capability to prevent structural damage from excessive acceleration. Projected longer range plans require the transfer of men between low and high earth orbits in the mid-to late nineties and past the year 2000.

The most demanding future mission requirement is the "manned GEO sortie," in the mid-90's. For this mission there would be a capsule attached to an OTV in which there would be a crew of two and supplies for about a week's stay at GEO. Additional equipment may be needed, depending on the task undertaken (such as repair of a faulty communications satellite). The minimum weight of capsule and crew would be in the order of 10,000 pounds and it may be as much as 13,000 pounds for a practical replenish/repair mission in which several GEO satellites are serviced. Space basing of a large OTV may be required to accommodate such missions.

The collective trends illustrated as a result of the current analysis of earth orbiting payload requirements show that in the late 80's, a need will exist to deliver payloads greater than 5,000 pounds into geosynchronous orbits and that the existing vehicles of the 1980's will determine the spacecraft designs of the late 1980's and the early 1990's. The results also indicate that geosynchronous spacecraft development/growth rate was slowed considerably during the last decade. Should a higher performance vehicle become available at affordable per flight cost, by 1985, spacecraft requirements will grow, and effectively utilize the carrier capability in the late 1980's.

4.1.3 PLANETARY PROGRAM REQUIREMENTS

4.1.3.1 Introduction

The selection and provision of upper stage capability for escape from low earth orbit are critical to solar system exploration. This section summarizes NASA's requirements of Shuttle upper stage options with regard to the future of planetary and solar exploration. The companion subsection of Section 5.0 assesses the impact of each upper stage option under consideration.

Factors influencing the selection and development of new propulsion systems include capability, availability, cost, and interface compatibility. We assume here that all proposed upper stage options are, by design definition, compatible with Shuttle Orbiter constraints and will be available on schedules stated elsewhere in this report. The cost trades between the various stage options are addressed elsewhere in this report. Specifically considered here, then are the capability and availability of the upper stage options as they affect approved and planned solar system exploration.

Interplanetary missions are particularly sensitive to propulsion capability since it dictates the flight path the payloads must travel to their destinations. The design of these missions usually begins with the use of "optimum" trajectories which reach the target destination at specified times (and locations) with minimum additional spacecraft propulsion capability. Once the upper stage capability and availability are factored in, however, trajectory adjustments must usually be made to "recapture" the mission. These adjustments often result in constraints or degradations to the original mission design expressed in terms of (1) added trip time, (2) more launches (i.e., the payload must be split into two parts to match upper stage capability), (3) deferred launches (an acceptable upper stage isn't available yet), (4) use of specific launch opportunities (low-energy gravity-assisted trajectories with increased risk must be used), (5) the addition of higher energy spacecraft propulsion to shift energy requirements away from the upper stages, and/or (6) reduction in mission objectives, and associated hardware or energy requirements, to stay within available upper stage capability. All of these considerations are used in this assessment of Shuttle upper stage options.

Beyond the concern for meeting upper stage requirements of current approved missions, selected stage capability will strongly influence the future direction of solar system exploration. A brief assessment was performed to determine the degree of impact stage selection might have on the exploration program over the next twenty years. For this purpose a group of ten mission objectives, representing anticipated accomplishments from 1985 to 2000, was defined as a "reference" mission set. This set of objectives is as follows:

1. Galileo Jupiter Orbiter and Atmospheric Probe
2. International Solar Polar Mission (ISPM) - (ESA Spacecraft)
3. Venus Orbit Imaging Radar Mission
4. Asteroid Multi-Rendezvous
5. Short-Period Comet Rendezvous
6. Mars Geochemical Orbit Mapping
7. Mars Surface Network Science
8. Mars Sample Return
9. Saturn Orbiter with Atmospheric and Titan Probes
10. Atmospheric Probes of Uranus and Neptune

Apparent in the list, is the fact that the first three objectives represent the present base of missions in NASA's approved program for solar system exploration. Beyond the currently approved missions, the set includes two small body rendezvous missions to explore several asteroids and to explore a short-period comet. Three missions to Mars represent a continued interest in the inner planets. They include global geochemical mapping and selected surface investigations (network science) as precursor objectives to a sample return mission. For the outer planets, a Galileo class orbiter to Saturn is included with entry probes for the planet and its satellite Titan. Two reconnaissance objectives to probe the primordial atmospheres to Uranus and Neptune complete the list. It must be emphasized that this "reference" set of mission objectives is not a proposed 20-year program for exploration. Rather it is thought to be representative of solar system exploration activity in the remainder of this century, and therefore is used to assess the impact of Shuttle upper stage capability on such exploration.

In the subsections which follow, an overview of upper stage requirements is presented first in the familiar terms of (injected) payload mass and escape energy. The specific impacts of the considered upper stage options on the three currently approved solar system exploration missions, i.e., Galileo, ISPM, and VOIR, are then addressed in Section 5.2.2. Finally, the broader scope of exploration capability over the next 20 years was examined considering each upper stage option individually, with and without SEPS (Solar Electric Propulsion Stage), and the results are presented in Section 5.2.2.

4.1.3.2 Overview of Upper Stage Requirements

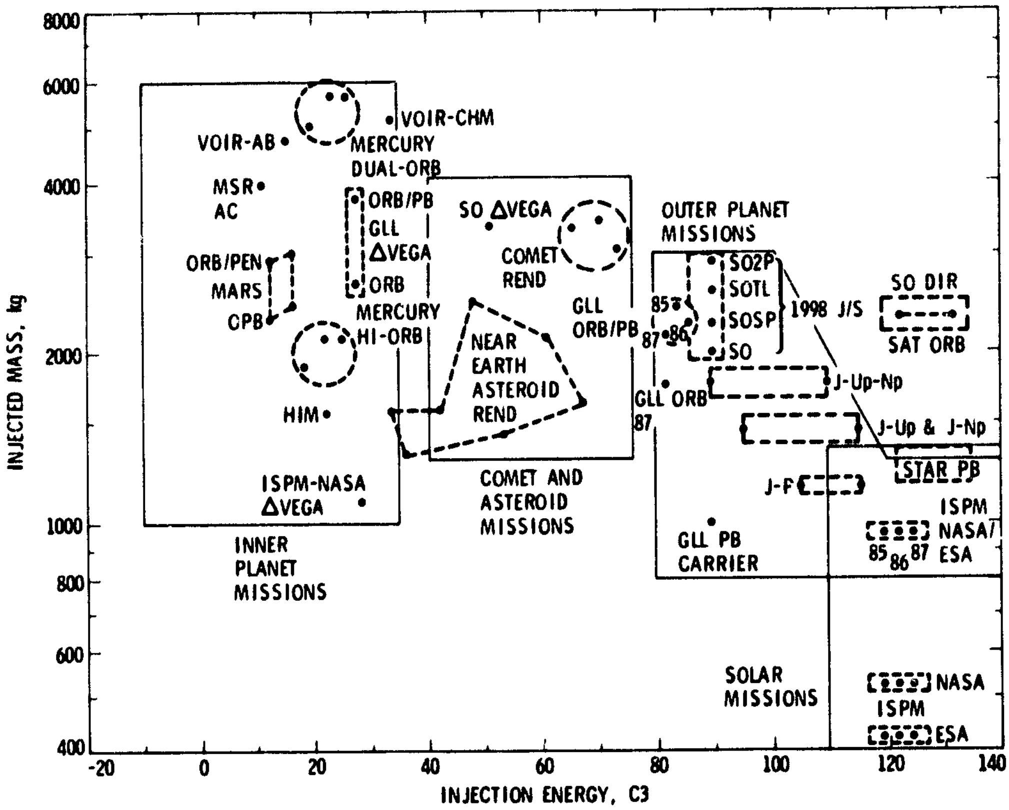
Earth escape propulsion capability is commonly expressed in terms of the amount of mass (payload) which can be delivered by an upper stage to a specified escape energy (C_3 which equals $(Km/Sec)^2$). The escape energy parameter, C_3, is the square of the excess velocity leaving earth and is a direct function of the upper stage impulse, the orbit at which the impulse is made, and the earth's gravity. At a C_3 value of zero the payload barely escapes the earth's gravity, and will not leave the earth's heliocentric orbit in the solar system. For positive values of C_3, interplanetary flight becomes possible. Negative values of C_3 are possible and indicate that the upper stage has added insufficient energy to the payload for earth escape. If the payload itself includes propulsion capability, however, it may still be capable of escape. In these instances the payload is said to include a "kick" stage to affect the final impulse necessary for escape.

To establish quantitatively escape performance requirements to measure against upper stage capability, a graphical format of injected mass (escape payload) and injection energy (C_3) is used. This format is presented in Figure 4.1-3. Within the figure, four regions are shown which bound the upper stage requirements of (1) inner planet missions, (2) comet and asteroid missions, (3) outer planet missions, and (4) solar missions. These regions assume a ballistic flight mode (i.e., interplanetary coasting) and include most of the solar system exploration missions presently under consideration.

There are, however, a few missions, e.g., multiple asteroid rendezvous, not included in Figure 4.1-3, and a number of others shown within the regions of 4.1-3, which require special launch opportunities and/or intermediate planetary swingbys. Figure 4.1-4 shows how the additional use of low-thrust interplanetary transfers using SEPS affects the size and content of these regions. Each of the original four ballistic regions is smaller in injected mass (vertical axis in Figures) extent, this being the consequence of removing propulsion-intensive missions from them. The fifth region in the upper left-hand corner of the figure contains all the low-thrust SEPS missions.

FIGURE 4.1-3

PLANETARY ENERGY REQUIREMENTS WITHOUT SEPS CAPABILITY



Comparing Figures 4.1-3 and 4.1-4 it is seen that the inclusion of SEPS reduces the payload requirements of the three higher energy mission regions which reduces the demand on upper stage performance. Without elaboration, SEPS also enables missions (e.g., single launch multiple asteroid rendezvous) and frees others from unique launch opportunities (e.g., Mercury and Saturn orbiters). In summary, these advantages result from splitting the ballistic escape-energy requirements with SEPS which delivers seven to ten times more impulse per pound of propellant than the chemical upper stages.

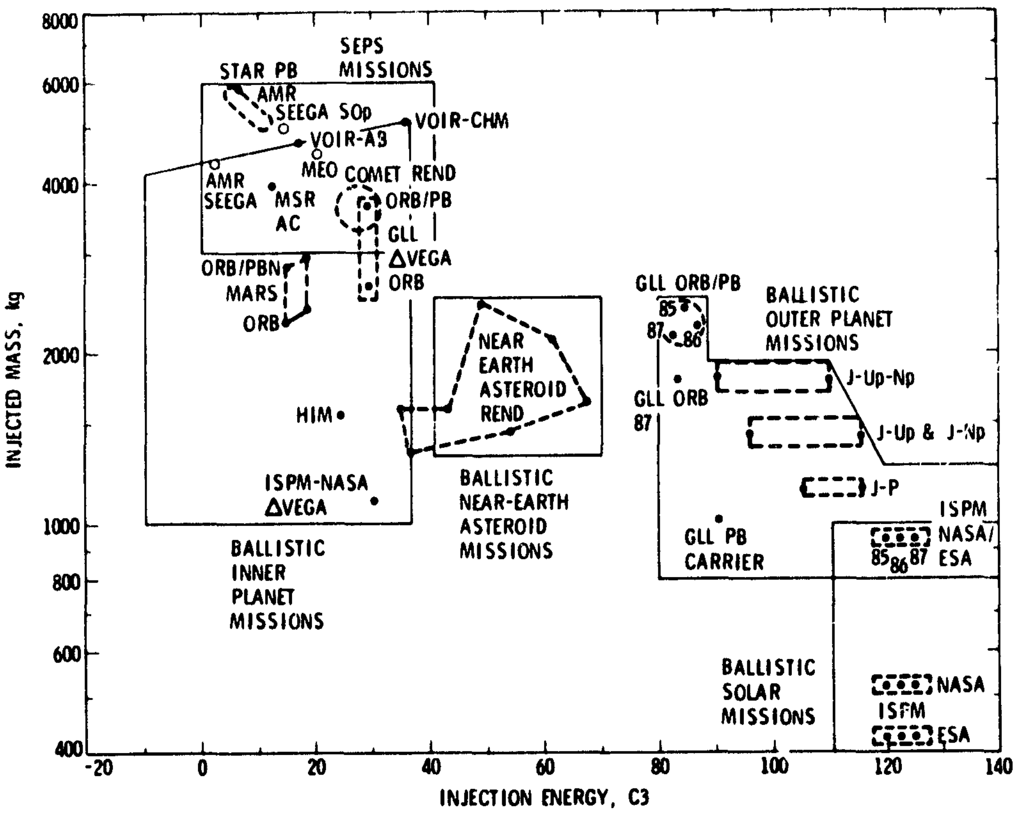
Relative to schedules and firm mission requirements, the Galileo is an approved mission and is currently funded and scheduled for launch in April 1985 on the Centaur STS. The design of the spacecraft hardware is essentially complete and any delays caused by carrier availability and/or carrier performance capability would drive the cost up considerably. These aspects are addressed later in the report in the assessment section.

The ISPM mission is an approved mission for 1986 whereby ESA is providing the spacecraft and the U.S. is providing the transportation system. This is considered a firm committment with the U.S. government by ESA and any further delay or impact relative to accomplishing the transportation requirements could be detrimental to future U.S./foreign joint space/scientific ventures. ESA is currently planning spacecraft interface compatibility with the Centaur STS.

The VOIR mission is planned for 1988. The energy requirements can most efficiently be met with a cryogenic upper stage. The assessment of launch alternatives in section 5.2.2 provides detailed assessment data relative to performance satisfaction.

FIGURE 4.1-4

PLANETARY ENERGY REQUIREMENTS WITH SEPS CAPABILITY



4.2 DOD UPPER STAGE REQUIREMENTS

4.2.1 INTRODUCTION

The requirements for upper stages to support DOD missions are strongly influenced by the nature of defense space satellite missions. The defense space satellites represent a wide variety of mission types and orbits which are, to varying degrees, critical to the defense and, therefore, the survival of the United States. In addition, each of the defense spacecraft programs has a mission that is of a continuing nature. The technical requirements which each spacecraft program must satisfy are influenced by the Soviet threat so that the technology, and therefore, the spacecraft configuration (size and weight) may vary over time. In general, programs are implemented by having periodic "block changes," (a block change is a major increase in spacecraft capability) with intervening evolutionary changes which tend to cause slow growth in spacecraft weight and capability until a major mission requirements change results in another spacecraft block change at a later time. Those defense space programs requiring an upper stage are currently preparing for their transition to the Space Transportation System/Intertial Upper Stage. Many programs have taken advantage of the STS opportunity in order to undergo a mission block change which has resulted in significantly larger and more capable spacecraft than have hitherto been employed. The discussion of specific defense space programs and their missions has been excluded from to this report. That information is available to those people with the appropriate security clearances and a specific "need to know."

4.2.2 SHUTTLE CAPABILITIES AND CONSTRAINTS

The Space Shuttle offers many new and unique capabilities which promise to fundamentally alter the nature of defense space activities. These Shuttle capabilities, when combined with the continuing operational objectives discussed in the preceding paragraph, can be used to enhance the overall probability of mission success for defense spacecraft programs. Specifically, this means using the Shuttle capability to support spacecraft and upper stage checkout prior to release; using the Shuttle on-orbit loiter capability to support a release later in the mission; or when necessary, using the Shuttle abort capability to return with the spacecraft and upper stage. This approach leads to mission planning based on the launch scenarios as shown in Figure 4.2-1. Because of the mission and cost impacts of delays in launch and deployment, the Air Force has expended considerable effort to maximize the chances for a successful deployment on the first flight, but with careful consideration to the reflight if an abort landing should occur. The upper stage requirements discussed in the following sections will be heavily influenced by these considerations.

FIGURE 4.2-1

OPERATIONAL LAUNCH SCENARIOS (SPACECRAFT WITH UPPER STAGE IN SHUTTLE)

PRIORITY OF MISSION EXECUTION	COST IMPACT	OPERATIONAL BENEFITS
Launch & deploy as planned	None	Achieved on schedule
Launch as planned, deploy later in mission	Extended STS mission costs ($1-10M)	Virtually on schedule
Launch, fail to deploy a working spacecraft, abort mission successfully, refurbish & refly spacecraft	Spacecraft & upper stage refurbish & reflight costs ($50-150M)	Delayed by months
Launch, deployment, or abort failure with spacecraft lost	New spacecraft & upper stage costs plus reflight costs ($200-400M)	Major delay - months to years

Shuttle constraints also must be considered in system design and operation. For example, the Orbiter payload bay volume is a major constraint; 60 feet is an absolute maximum and it must accommodate both the spacecraft and its upper stage. Shuttle payload weight limits (65,000 pounds to a 28^{o} inclined orbit) will become a significant constraint for higher energy upper stages since propellant weight (which is the bulk of the upper stage weight) grows rapidly with increases in performance capabilities. This limit is a significant factor in evaluating the upper stages in this report. Over the longer term, the Shuttle weight constraint will need to be eased by increasing Shuttle performance, by using new orbital transfer techniques such as solar-electric propulsion, or by joining the spacecraft and upper stage on-orbit with two Shuttle flights. Indeed, a combination of these techniques will probably be needed to meet 21st century requirements.

4.2.3 DOD STUDY APPROACH

The DOD upper stage requirements analysis has been conducted on a qualitive basis; a more definite, quantified approach could not be accomplished in the time available for this study. The wide range of potential options makes a highly quantitative approach extremely difficult, if not impossible, since it is unclear what mix of payload programs would be assigned to any specific upper stage. The upper stage requirements are still a complex set, and it is necessary to

consider each requirement essentially independently from the others in order to assess the various upper stage candidates. In reality, the requirements are interactive with each other, vary in criticality based on the spacecraft programs assigned to a specific upper stage, and can change significantly if a different technical solution is found to a particular problem. Given these limitations, the Air Force has performed as rigorous an assessment as possible.

The Air Force conducted a detailed survey of all operational defense spacecraft programs and asked them to specify their upper stage requirements using the format shown in Figure 4.2-2. In each case programs defined their requirements as "firm" (i.e., necessary to support budgeted program activities) or as "desired" (unconstrained by budget, but based on the program manager's judgement as to how he could best fulfill his mission objectives). Each spacecraft program prepared an assessment in the format of Figure 4.2-2. The operational spacecraft program requirements have been accumulated into a single set of upper stage requirements and are shown in Figure 4.2-2. The specific requirements and their rationale will be discussed later in this section. It is essential to satisfy the firm requirements levied on the upper stage by these operational DOD payloads since they represent existing missions; we must also consider the desires (Figure 4.2-2, Column 3) of these programs since these often become funded, firm, requirements at a later time.

The Air Force also performed an assessment of advanced program concepts. Generally, these represent ideas for potential post-1990 DOD missions which have only received limited study and which are limited to a relatively simple concept definition and first order estimates of the payload size and orbits required in order to conduct missions of this nature. Such an advanced concept might include the use of a maneuverable vehicle to repair defense spacecraft in various orbits. The upper stage requirements for selected concepts are shown in Figure 4.2-3. This shows the implications that such missions, if approved, might have on defense upper stage requirements in the 1990's and on into the 21th century. These concepts are used primarily as a "boundary condition" check in terms of upper stage selection; that is, as a means of assessing whether any given upper stage option could logically grow to satisfy such needs or whether it would reach its limitations before it could satisfy these long term requirements. These long term requirements might help choose the appropriate path to follow in the near term.

In addition, we have considered other factors not directly related to mission per se--such as the possibility of operational contingencies where only one of the two Shuttle launch sites is available--and have attempted to apply some experience and judgement to our long term projections.

4.2.4 DOD UPPER STAGE REQUIREMENTS

In this section we define, and briefly discuss the rationale for, each of the upper stage requirements shown in the left hand column of Figures 4.2-2 and 4.2-3. We also present a summary of those requirements as a function of time over the rest of the 20th century.

Performance requirements: These include the payload weight placed in final orbit and the accuracy with which it is placed there. All requirements in this section are presented in "geosynchronous equivalent" performance.

Currently approved and funded DOD operational space programs require 5,000 pounds placed in a geosynchronous orbit (that is, an orbit such that the spacecraft stays at a point over the equator). Projections of firm requirements for operational defense programs indicate this requirement will grow to 5,500 pounds in the late 1980's. Furthermore, these operational DOD programs would like to have a capability of 5,500 pounds in 1987, growing to 6,200 pounds in 1988, with at least one program projecting a block change (with a spacecraft potentially weighing 8,000 pounds) in 1990. Payload weight in final orbit is the most important discriminator between stages; limited weight capability can force mission limitations or increase spacecraft cost to implement weight reduction programs.

The accuracy at which the spacecraft is placed in its final orbit includes its position (or precise location), the residual velocity at that point in space, and its inclination (the angle the orbit makes the equator). Operational payload programs are showing requirements for placement accuracies approximately twice as good as the specification requirements levied on current stages; these tighter requirements are reflected in Figure 4.2-2. Placement accuracy is an extremely important parameter since errors must be overcome by using spacecraft propulsion capability. The greater spacecraft adjustment needed the greater the impact on the ultimate on-orbit life of the spacecraft. Hence, there is direct relationship between placement accuracy and spacecraft life, and increased spacecraft on-orbit life translates directly into both increased operational effectiveness and lower program costs for each spacecraft program. There is an interaction between injection accuracy and payload weight capability of the upper stage in that excess payload weight capability can be used to provide additional spacecraft propellant for orbit adjustments and--to some degree--reduce injection accuracy requirements.

Operational requirements: In addition to the critical performance requirements, the nature of defense space programs results in a number of additional operational requirements which must be considered in development and deployment of an upper stage. The Shuttle, with its flexibility and its payload return capability, opens a totally new approach to planning and executing operational space launches. The upper stage design must take this into account and much of the following discussion builds on these objectives.

FIGURE 4.2-2

STS UPPER STAGE REQUIREMENTS FOR OPERATIONAL DOD PAYLOADS

REQUIREMENTS	CURRENT CAPABILITY (SPEC)	APPROVED PGM (FY 82PB/FYDP)		PLANNED PGM (FY 83-87 POM)		DESIRED PGM		REMARKS
		PROGRAM RQMT?	QUAN-TIFY *	PROGRAM RQMT?	QUAN-TIFY *	PROGRAM RQMT?	QUAN-TIFY *	(Specify year for new Rqmts)
PERFORMANCE								
Payload Weight	5,000 lbs (geo)	R	5000	R	5500	D	5800 8000	5800 in 1987; 6200 in 1988; 8000 in 1990
Position Accuracy	92 NM	R	53					Mid-85
Velocity Accuracy	78 Ft/Sec	R	45					Mid-85
Inclination Accuracy	0.12°	R	0.06					Mid-85
OPERATIONAL								
Max Launch Reliability	96%	R						
Adaptive Guidance	Yes	R						
Load Alleviation	Yes - Soft Mnt Cradle	R						
Orbiter Bay Loiter	Up to 7 Days	R						3-7 days capability requested by various spacecraft programs
Payload Length	42 Ft	R						
Orbit								
Geosync	Yes	R						
12 hr elliptical	Yes	R						
Other (specify)	Yes	N						
Predeployment checkout	Yes	R						Visual, & Via Upper Stage Telemetry
S/C Services	Yes	R						Command, Telemetry, Power
Storable	No	N						
S/C Recovery	No	N						
Engine Restart	No	N						
Large Mission Box	Yes	R						
Launch Call-up	Yes	R	60 dys					
Multiple Deployments	Yes	R						
Rendezvous	No							
OTHER								
Mech/Elec I/F	TIIIC equivalent	R						
Restow Capability	Yes	R						
Higher Park Orbit	No					300x100	1984	

Pgm Rqmt Code: R - Required Mandatory
D - Desirable
N - Not needed

*Quantify capability desired if different from current capability

FIGURE 4.2-3

PROJECTED STS UPPER STAGE REQUIREMENTS FOR POTENTIAL POST-1990 DOD MISSIONS

REQUIREMENTS	CURRENT CAPABILITY (SPEC)	CONCEPT A PROGRAM RQMT?	CONCEPT A QUAN-TIFY *	CONCEPT B PROGRAM RQMT?	CONCEPT B QUAN-TIFY *	CONCEPT C PROGRAM RQMT?	CONCEPT C QUAN-TIFY *	REMARKS (Specify year for new Rqmts)
PERFORMANCE								
Payload Weight	5,000 lbs (geo)	15,000	1998	38,000	2006	8000	1994	See orbit requirements below
Position Accuracy	92 NM	R		R		R		
Velocity Accuracy	78 Ft/Sec	R		R		R		
Inclination Accuracy	0.12°	R		R		R		
OPERATIONAL								
Max Launch Reliability	96%	R		R		R		Should be even better than 96% in long term
Adaptive Guidance	Yes	D		D		R		
Load Alleviation	Yes - Soft Mnt Cradle	R		R		R		
Orbiter Bay Loiter	Up to 7 Days	D		D		D		Could be even greater in the long term
Payload Length	42 Ft	D		D		D		
Orbit								
Geosync	Yes	-		-		R		
12 hr elliptical	Yes	-		-		R		
Other (specify)	Yes	100K mi 90°		60K mi 60°		R-multiple		
Predeploy-ment checkout	Yes	R		R		R		
S/C Services	Yes	R		R		R		
Storable	No	N		N		D		
S/C Recovery	No	N		N		R		
Engine Restart	No	N		N		R		
Large Mission Box	Yes	N		D		R		
Launch Call-up	Yes	R		R		R		
Multiple Deployments	Yes	D		D		N		
Multiple Rendezvous		N		N		R		
OTHER								
Mech/Elec I/F	TIIIC equivalent							

Pgm Rqmt Code: R - Required Mandatory
D - Desirable
N - Not needed

*Quantify capability desired if different from current capability

Reliability requirements are based on a 96 per cent probability of launch success. High reliability is extremely important in reducing the number of spacecraft lost due to launch failure. Each spacecraft lost results in some degredation of capability - ranging from tolerable to catastropic. Consequently, we attempt to minimize the loss of critical operational spacecraft at launch and thus minimize the period in which the operational spacecraft capability is lost. The goal of maximizing launch success is achieved by a combination of high quality components and redundant systems. The effects of this approach goes beyond the increase in "calculated" reliability (which is based upon the reliability of individual components). Figure 4.2-4 illustrates the benefits; eleven earlier launch failures (5 Transtage and 6 Centaur) were analyzed based on the cause of failure. A redundant system would have resulted in eight of those eleven failed launches being successful. Further, the average cost of defense spacecraft, combined with their launch cost, ranges from a low of approximately $200M per flight to a high of perhaps $400M per flight (in FY 81 $). The variation in cost is due to the differences in the cost of individual spacecraft, which range from a low of about $100M to a high of about $300M each, the balance is made up of launch related costs (Shuttle flight charge, upper stage buy, integration and launch services). Consequently, there are significant economic benefits in addition to the operational benefits, of maintaining a high probability of launch success.

FIGURE 4.2-4

BENEFITS OF REDUNDANCY (GEOSYNCHRONOUS MISSIONS)

LAUNCH FAILURES	COULD REDUNDANCY PREVENT FAILURE?	
TRANSTAGE		
A-2 Valve Open	Yes	R&D Launches
C-4 Frozen Bi-propellant Valve	Yes	R&D Launches
C-8 ACS Valve Open	Yes	R&D Launches
C-17 Inadvertent software discrete switched valve off - internal redundancy avoided mission failure		
C-19 Inertial Measurement Unit Gyro Drift	Yes	
C-25 Inertial Mesurement Unit Transistor Shorted	Yes	
Five out of five Transtage failures could have been prevented by redundancy		
CENTAUR		
AC-3 Hydraulic Pump Drive	Yes	R&D Launches
AC-4 LH_2 Vent Instability	No	R&D Launches
AC-8 Attitude Control System Leak	Yes	R&D Launches
AC-17 No 2nd Burn - Boost Pump Froze	No	
AC-24 Autopilot Tumbled	Yes	
TC-1 LO_2 Boost Pump Froze	No	
Three out of six Centaur failures could have been prevented by redundancy		

The requirement for adaptive guidance is based on an accumulation of factors including the multiple types of orbits required for the range of defense spacecraft and the opportunity presented by the Space Shuttle to allow two or more chances for deployment and a successful mission should the initial planned deployment not be possible for some reason. Consequently, in order to simplify the operational use of an upper stage, and to minimize future software changes, a relatively generalized guidance scheme is needed. This range of requirements, while it can be mechanized in other ways, is important to meeting all defense requirements efficiently over a long period of time.

Load alleviation systems are an essential element for a defense upper stage using the Space Shuttle. This enables the spacecraft, some of which have relatively fragile structures, to survive both launch and abort landing loads. This insures that the spacecraft is available in a short time after an abort for reflight to meet its operational requirements. Further, each mission not lost due to an abort represents a considerable programmatic savings, ranging from $200M to $400M (including spacecraft savings of $100M to $300M).

Defense upper stages must be capable of remaining in the Orbiter bay for up to seven days prior to deployment. This takes advantage of a new opportunity presented by the Shuttle so that, if the original planned deployment is not made, the upper stage will be capable of remaining in space with the Orbiter and the spacecraft up to the limit of the Orbiter capability -- which is now seven days. In this way we maximize the number of possible opportunities to successfully deploy the mission, thus preventing the need for a return, landing, refurbishment, and reflight. This has the effect of providing the spacecraft in operational use earlier than it would be available should an abort have been required, and eliminates the cost associated with an abort and reflight.

Available payload length is a critical factor for a number of defense missions which have spacecraft whose length approaches 42 feet, allowing only 18 feet of the Shuttle payload bay for an Upper Stage and deployment mechanisms. Several payload programs have mission and technical requirements which could not readily be satisfied with current technology (or without a significant increase in development costs) if payload space were severely curtailed. Thus, the physical length of an upper stage is a critical factor for defense missions.

Defense spacecraft operate in a widely varying range of orbits. For example, geosynchronous orbits provide unique opportunities for worldwide communications and 12 hour elliptical orbits provide a unique capability for conducting communications in polar regions which are not accessible to geosynchronous satellites. Defense missions employ these orbits, as well as others, as an essential means of meeting their mission requirements. Thus the upper stage must be capable of deploying spacecraft at any desired location.

The capability to conduct predeployment checkout of the spacecraft and upper stage represents yet another unique opportunity provided by the Space Shuttle. This checkout is conducted in the Shuttle bay prior to release of the spacecraft/upper stage combination. If the spacecraft has failed in some substantial way during the Shuttle ascent phase of the flight it is possible to return and repair the spacecraft for another launch thus preventing the complete loss of a valuable spacecraft and the loss of its operational capability.

Defense spacecraft require specific upper stage services such as telemetry, power, and limited commanding capability in order to conduct the predeployment checkout, to otherwise ensure that spacecraft is healthy, and provide an opportunity to recover the spacecraft. This requirement comes from several sources; the NASA desire to maintain simple Shuttle interfaces, the DOD desire to make Shuttle transition as easy as possible for the spacecraft programs, and the need to provide a backup expendable launch vehicle capability during Shuttle transition. Consequently, all DOD spacecraft using an upper stage are configured such that they have no direct interface with the Shuttle Orbiter. All spacecraft services are provided by the upper stage which also provides all interfaces to the Orbiter. These services are another important element in taking advantage of the opportunities provided by the Space Shuttle.

The capability to provide long term on-orbit storage of an upper stage is not currently a part of defense mission requirements. However, several programs have analyzed this technique as a means of protecting against possible Shuttle outages or groundings. Indeed, one program elected to employ an integrated propulsion system with a secondary reason being the desire to avoid having the upper stage provide an electrical power system capable of indefinite on-orbit storage. Current defense missions involve the launch and deployment of a satellite which takes place in a relatively short (hours as opposed to days or weeks) period of time. An upper stage containing storable propellants, and long life electrical power, would have benefits for high energy maneuvering should it be required after a long period on orbit as a means of threat avoidance.

Spacecraft recovery is not a requirement of current high altitude defense programs. High altitude spacecraft using an upper stage have very long lives (from about three to seven years), and at the end of their useful operational lives are of relatively limited mission value and are replaced by spacecraft with significantly greater technical capabilities. Further, the cost of launch and recovery is a large percentage of the spacecraft cost. Consequently, current high altitude missions do not find spacecraft recovery operationally or economically attractive. Over the long term, however, as larger and more complex systems are deployed and maintained for an extended period of time, recovery of these spacecraft may become more economical.

Multiple upper stage engine starts for the purpose of on-orbit maneuvering (other than for deployment of the spacecraft into an operational orbit) are not currently required by defense space programs. However, as spacecraft survivability considerations become more important, this capability could also grow in importance.

A number of defense missions have a requirement for wide variation of potential orbit positions. This is known as "large mission box." This has the effect of placing significantly greater demands on the guidance system for the upper stage and on the operational process of planning and conducting spacecraft launches since the precise launch target will not be defined until very near the launch date.

Launch call-up is required for a number of defense missions because of the essential need to maintain a continued on-orbit capability. Should sudden failures occur in operational spacecraft it is necessary to bring a new spacecraft through final processing and launch in a short period of time. Failure to do so could seriously jeopardize our national defense by allowing critical defense space capabilities to be lost and thus have large coverage gaps for an extended period.

Some defense spacecraft programs require the deployment of multiple satellites on a single launch. This also results in reduced spacecraft program costs by distributing launch costs over a larger number of on-orbit satellites.

No current operational defense program requires the ability for the upper stage to rendezvous with the spacecraft once it has been deployed in orbit. This rendezvous capability may have long term potential for future missions.

Other requirements: In addition to the performance and operational requirements discussed above, a number of other significant demands are placed on the upper stage design.

Three axis stabilization, (the ability of the stage to maintain a fixed orientation in space without spinning) is essential for the launch of most defense satellites. This stabilization approach gives the spacecraft designer considerably more freedom in configuring his spacecraft to handle the significantly different demands of launch and on-orbit operations, and that results in a significantly lower cost to develop the same operational capability.

A capability to restow the spacecraft/upper stage combination in the Shuttle bay is essential to take full advantage of the Shuttle opportunity for recovery and reflight of a failed mission. If a restow capability is not designed into the system, and spacecraft deployment cannot be accomplished after the spacecraft is erected, then it would be necessary to abandon the spacecraft and upper stage in order to close the orbiter bay doors prior to reentry. This would result in the loss of a valuable spacecraft and upper stage.

The Shuttle park orbit currently is planned as a 150 nautical mile circular orbit. This provides a firm baseline from which all spacecraft and upper stage designers can work. A higher Shuttle park orbit is not part of the current program baselines. However, the higher park orbit has the potential--by more efficiently using the Shuttle energy--to increase the payload ultimately placed in final orbit without any modifications to the payload, the upper stage, or the Shuttle itself.

4.2.5 DOD REQUIREMENTS SUMMARY

A review of the requirements for operational defense space programs and for conceptual post 1990 defense missions (as shown in Figures 4.2-2 and 4.2-3) allows us to draw several conclusions.

Operational defense space programs (Figure 4.2-2) have indicated a need for all of the capabilities which are part of the current baseline specifications levied on the Inertial Upper Stage when used in the Space Shuttle. Further, no spacecraft program has indicated a requirement for any capability not currently included in the DOD upper stage requirements such as long term on-orbit storage, multiple burn, or rendezvous. Defense space programs have stated a requirement for higher orbital injection accuracies than current specifications demand, and also project firm growth to approximately 5,500 pounds by 1987 based upon their currently funded (approved and planned columns in Figure 4.2-2) program activities.

These operational programs also project the possibility, although not currently in the program funding, of growth to approximately 5,800 pounds by 1987, to about 6,200 pounds in 1988, and with the potential for 8,000 pound spacecraft in geosynchronous orbit in 1990.

As space systems become increasingly vital to our defense effort, we must also consider the potential need for contingency launch operations in which only one Shuttle launch site is operational. In wartime, or other national emergencies, we could launch selected missions from either the Kennedy Space Center or Vandenberg AFB. In particular, since all our upper stage operations are at Kennedy, all the defense missions discussed in this report are normally launched from Kennedy. If sufficient energy were available both from the Shuttle and from the upper stage, we could launch high altitude defense missions from Vandenberg AFB.

The conceptual post 1990 defense missions (Figure 4.2-3) show dramatic growth in payload weight combined with extremely high energy orbits. Payload weight can be expected to grow to perhaps ten times current levels, and be combined with extremely high altitude orbits. This will place extreme demands on the launch systems, driving them to maximize their efficiency and performance. Such missions are well beyond the capability of any existing or planned upper stage and might even require, in addition to a large upper stage, the possibility of on-orbit rendezvous of the upper stage and payload, the use of a solar electric propulsion system to supplement the chemical propulsion upper stage, an increase in space shuttle weight capability beyond 65,000 pounds, or new launch vehicles larger than the Shuttle. In addition, these missions also show in some instances where it may be desirable to have storable propellants in an upper stage and where spacecraft recovery, upper stage engine restart, and multiple rendezvous capabilities would clearly be needed. Consequently, the demands on the next generation of upper stages will be significantly greater than those placed on the current generation.

SECTION

5.0

UPPER STAGE ASSESSMENTS

5.0 UPPER STAGE ASSESSMENT

5.1 INTRODUCTION

Up to this point in the report, which followed the study sequence of events, the basic requirements or national needs of spacecraft developers, satellite users, etc... have been examined for the near term and foreseeable future. With a reasonable understanding of the payload requirements, an assessment of payload requirements versus upper stage capabilities was conducted.

5.2 NASA ASSESSMENT

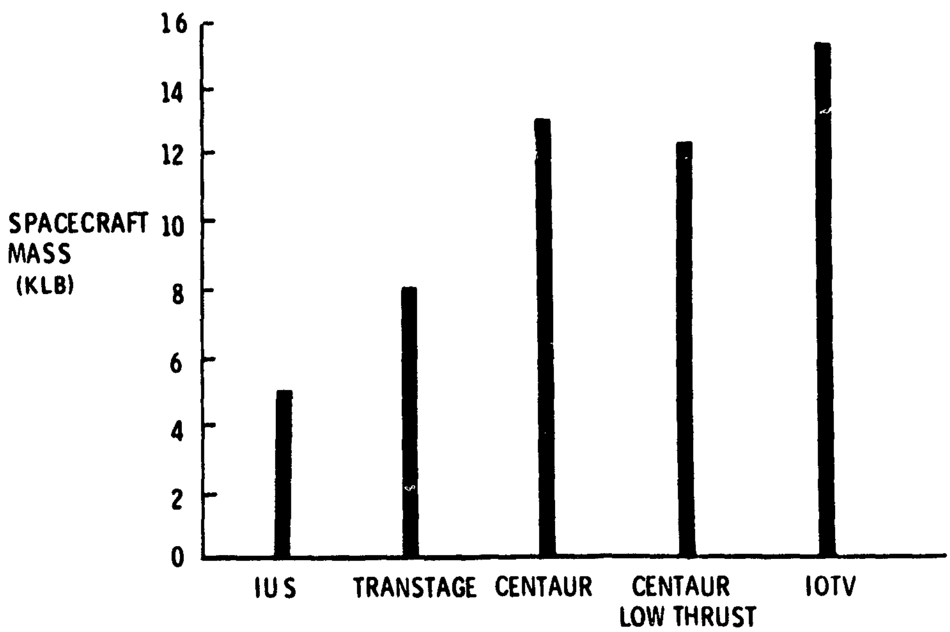
The NASA requirements include earth orbiting and planetary requirements for NASA and Commercial Spacecraft. Section 5.2.1 will discuss the capability of the STS upper stage options for meeting earth orbiting needs and Section 5.2.2 will provide the results of the assessment of launch alternatives, including use of expendable launch vehicles, for planetary missions.

5.2.1 NASA ASSESSMENT - EARTH ORBITING MISSIONS

As Section 4.1.2 discussed the earth orbiting mission requirements, this area of the report will show a comparison of STS upper stage options as they relate to deliverable mass in geosynchronous orbit.

Figure 5.1-1 shows a comparison of the mass to geosynchronous orbit for the primary STS upper stages.

FIGURE 5.1-1
STS UPPER STAGE
GEOSYNCHRONOUS ORBIT CAPABILITY



The IUS performance shown is for the current IUS Two-Stage vehicle i.e...5,000 pounds to geosynchronous orbit. Growth capability does exist for the IUS, even though it is a solid propellant vehicle. The delivery of 6,000 plus pounds is possible with modifications. Growth to 8,000 pounds is also considered possible with moderate development complexity. Additional growth beyond that point is limited by shuttle lift capabilities.

The storable propellant stage capability shown represents the STS Transtage with a 4 tank STS configuration. This is a viable option, but future growth beyond the 8,000 pounds is limited by shuttle lift capabilities and would not meet requirements such as planned for Intelsat VII, i.e... 9,000 to 12,000 pounds into geosynchronous orbit.

The Shuttle/Centaur as shown on the bargraph depicts the performance of the wide-body Centaur STS configuration as envisioned for the Galileo mission in 1985. The low thrust missions maintain the same configuration with operation of the engine in an idle mode. The Centaur, although high in mission performance, would have to be modified extensively to provide growth potential to an optimum OTV in the 1990's.

The Centaur's high energy capability would satisfy projected requirements well into the 1990's. With 4 years spacecraft development time, the spacecraft designers could fly as early as 1989 should they require flight demonstration for assurance that the stage is available prior to beginning spacecraft development. Positive program backing and or other incentives may provide earlier confidence such that users may invest earlier and fly earlier. The Intelsat VI spacecraft is scheduled to fly in 1986 and requires 4,400 pounds into geosynchronous orbit. It is being designed to be compatible with the Ariane and the STS. In the STS it could fly on either the IUS or the Centaur.

The IOTV, since it would be a new design, could have numerous new features, i.e.. redundant Guidance and Control Systems, a low thrust capability and dimensions optimized for the Shuttle. However, all these features would tend to add cost, reduce performance and increase schedule risk. With these features, our estimates indicate a development cost increase of about 50% more than the wide-body Centaur and a delay of 2-3 years in first flight.

In summary, the Centaur will meet mission needs for the foreseeable future and could be available at least two years earlier than an IOTV. As Centaur is already a proven reliable stage, the commercial world may waive the flight demonstration as a requirement for beginning spacecraft design. However, NASA would have to continue to provide firm program funding commitments for the Centaur STS, to provide the sound basis for early business investment in larger spacecraft. Other benefits of the Centaur and/or IOTV such as low thrust, multiple burn capability, use of propellant off loading to maximize unique mission compatibility with the Shuttle, etc... are also important considerations in favor of a liquid stage.

The storable and solid stages are limited to the degree that uprating programs would be required. None of these would lead to eventual OTV capability or provide experience which would be eventually useful relative to development of an OTV capability. They are "dead ended" programs as far as STS growth is concerned.

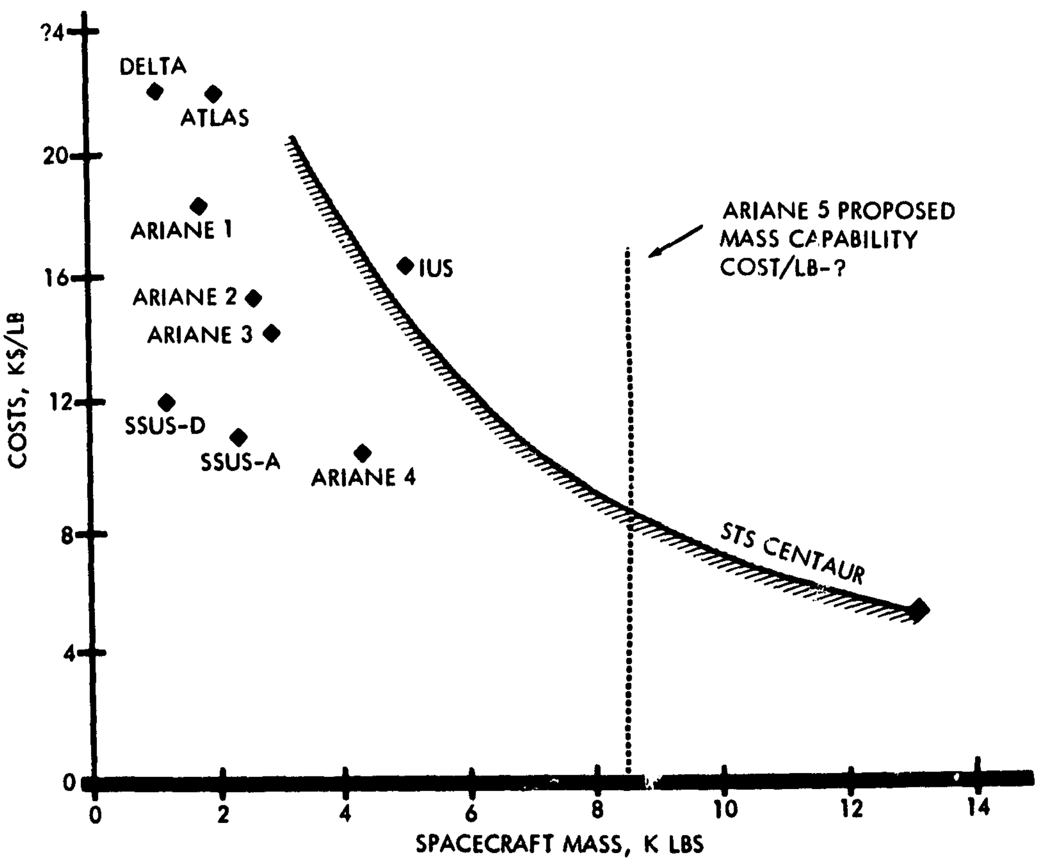
A cost benefits analysis was performed to show cost per pound to geosynchronous orbit with existing/planned systems. Figure 5.1-2 displays some of the results.

Results are that (1) the Centaur is not cost effective for currently designed payloads, i.e., spacecraft weights small for compatibility with the ELV capability, (2) Centaur could be cost effective for some currently designed spacecraft if multi-spacecraft per launch were considered, (3) the Centaur would be cost effective for new future spacecraft where spacecraft weight growth is not restricted for dual compatibility, i.e., ELV and STS, and (4) STS cost/pound to geosynchronous orbit decreases rapidly with increasing upper stage performance.

FIGURE 5.1-2

COST/LB vs SPACECRAFT MASS TO GEOSYNCHRONOUS ORBIT

POST 1985 LAUNCH -FY '80 DOLLARS



The role of the United States' leadership in technology and its application to selection of an appropriate upper stage was discussed in considerable detail during the study. In review of foreign planned launch vehicles, i.e., ESA's Ariane, the Japanese H-1 development, and China's launch vehicle efforts, it is obvious that foreign nation's upper stage technology and industrial base capability are advancing rapidly. The Ariane I vehicle has a cryogenic third stage (12,000 pounds of thrust) and the Ariane V will have a large cryogenic second stage. The Japanese are perfecting a cryogenic second stage which will have a specific impulse comparable to that of the Centaur. This rapid advancement in foreign technology is being fueled by the already existing multi-billion dollar commercial spacecraft launch business.

The cancellations or delay of the Centaur STS development, at this time, will eventually reduce the U.S. industrial base in cryogenic propulsion systems to a single company. Not only will the current technology and production capability for engines in the upper stage class no longer exist, but the domestic industrial base required for future advancement in cryogenic engines will be greatly impaired.

In final assessment of earth orbital commercial business requirements, a timely cryogenic upper stage capability similar to that which can be provided by the Centaur STS is justified if the United States is to maintain competitive status.

A development complexity and schedule risk factor analysis was also performed. Figure 5.1-3 provides a matrix view of the results. The major points considered are marked by an ellipse. The IUS is needed in 1982 by NASA fc the TDRS missions. The IUS two stage program is at the point in development and production where risk are low. The Centaur program has been initiated with an existing solid data base. As it is a derivative of a highly successful prior development, the schedule risks are considered moderate. The IOTV, being a new vehicle, would have a higher complexity factor and a greater schedule risk factor. Accordingly the availability date is 1987.

FIGURE 5.1-3
UPPER STAGE ALTERNATIVES
RISK ASSESSMENT

	POUNDS TO GFO	GROWTH POTENTIAL	MULTI-BURN	LOW THRUST	AVAIL-ABILITY	DEVELOP-MENT COMPLEX-ITY	SCHEDULE RISK
IUS	5000	--	NO	NO	1982	LOW	LOW
UPRATED 1	6000	--	NO	NO	1986	LOW	LOW
UPRATED 2	8000	LIMITED	NO	NO	1990	MODERATE	LOW
TRANSTAGE STS							
2 TANK	5000	--	YES	YES	1984	LOW	HIGH
4 TANK	8000	LIMITED	YES	YES	1985	LOW	HIGH
CENTAUR STS							
29 FT	13000	LIMITED	YES	YES	1985	LOW	MODERATE
20 FT	10600	LIMITED	YES	YES	1986	LOW	MODERATE
IOTV							
18 FT	13000	TO OTV	YES	YES	1987	MODERATE TO HIGH	MODERATE TO HIGH

5.2.2 UPPER STAGE MISSION ASSESSMENT FOR NASA PLANETARY PROGRAM

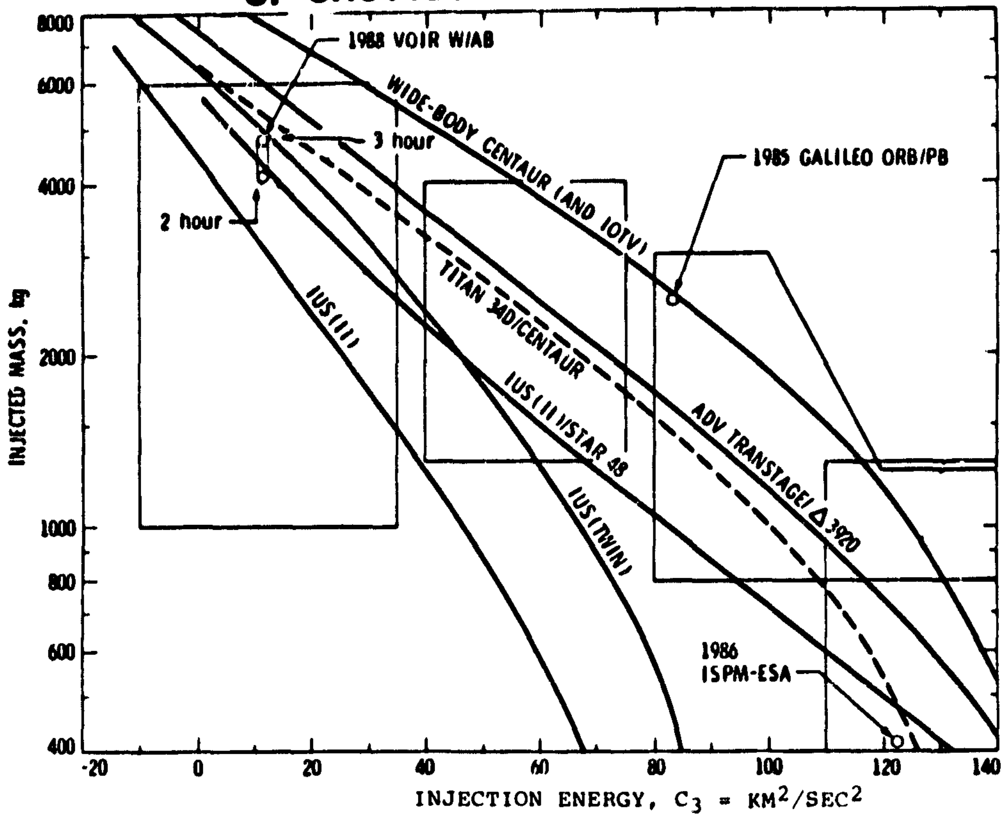
5.2.2.1 Introduction

Against the regions of solar system exploration mission requirements developed in Section 4, specific upper stage options can be compared. This is done in Figure 5.1-4 comparing upper stage performance curves against the four mission regions shown in Figure 4.1-3 (The additional specific benefits of SEPS are treated in Subsection 5.2.2.6 which addresses exploration performance requirements over the next 20 years). Five performance curves are shown for the following upper stage options:

1. IUS
2. IUS Star 48 kick
3. IUS (Twin)
4. Advanced Transtage/Delta 3920 2nd Stage
5. Wide-Body Centaur
6. IOTV

FIGURE 5.1-4

PLANETARY MISSION CAPTURE ABILITY OF SHUTTLE UPPER STAGES



Also shown as a dashed curve is the performance of the expendable Titan III (34D)/Centaur launch vehicle. Any mission whose injection point (i.e., injected mass and C_3) falls beneath an upper stage performance curve is "captured" by that upper stage. The wide-body Centaur (or equivalent IOTV) is obviously the best performing upper stage option and would capture most missions in all four regions. Next best is the Advanced Transtage closely followed by the Titan III (34D)/Centaur expendable vehicle. The IUS Star 48 is better than the IUS(Twin) at higher energies but not for the lower inner planet missions. For purposes of the subsequent impact analysis the difference at low energies was not a discriminator. As a consequence, the performance of the IUS Star 48 was assumed. The IUS falls below all regions except half of the inner planets region.

Also plotted in Figure 5.1-4, are the injection points for the three solar system exploration projects in the present NASA Five Year Plan which are as follows:

1. 1985 Galileo combined orbiter/probe mission
2. 1986 ISPM-ESA Spacecraft mission
3. 1988 VOIR with aerobraking mission

The Galileo mission is only captured by the wide-body Centaur (the IOTV is not available until 1987). The ISPM-ESA mission is captured by the IUS Star 48, Advanced Transtage, Wide-Body Centaur, and the expendable Titan III (34D)/Centaur. The VOIR mission with aerobraking would be captured by the Advanced Transtage, Wide-Body Centaur, IOTV, IUS Star 48 and the expendable Titan III (34D)/Centaur. A complete assessment of the possible upper-stage impacts on these three early Flight Projects is presented next.

5.2.2.2 Assessment of Early Mission Alternatives

The present NASA Five-Year Plan includes three Solar System Exploration Flight Projects which are Galileo, ISPM, and VOIR. The purpose of this discussion is to present the impact on these flight projects on upper-stage capability and availability and to assess the consequences of those impacts. The approach used in this assessment considers each project individually, presenting mission alternatives and comparing alternative mission characteristics to the current baselines. Results are then briefly summarized with respect to the upper stage options being evaluated in this study.

5.2.2.3 Galileo

We begin with the Galileo Jupiter orbiter and probe mission project. Six mission alternatives for Galileo are presented in Table 5.2-1. Case I, a 1985 launch of the combined orbiter/probe payload, arriving in mid-1987 is the present Project baseline. It is a direct flight to Jupiter requiring no additional injection or deep-space propulsion and has full orbit capability of 11 encounters with Jupiter's satellites. As seen in Table 5.2-1, it requires the wide-body Centaur upper stage for earth escape. This same mission could be launched with an IOTV with adequate performance. The earliest an IOTV could be ready would be 1987 (Case 2). If an IOTV did not have Centaur's performance the Galileo mission would have to be split once again into two separate STS launches or launched on a Δ-VEGA trajectory--in either case project Galileo cost increases would be substantial.

The next case is to split the mission (Case 3), launching the orbiter without the probe in 1985 on a Δ-VEGA trajectory and launching the probe with a newly procured carrier spacecraft a year later in June 1986. The orbiter must also be modified to include a payload kick stage. The resultant performance is equivalent to the IUS Star 48. The 11 satellite encounters are preserved but due to the launch delay, do not occur until almost three years later than the present baseline mission.

The next two cases, (4 and 5) recombine the orbiter and probe for a single 1985 launch using the Δ-VEGA flight mode to reduce upper stage requirements. Preserving the 11 satellite encounters (Case 4), requires the Advanced Transtage (or the Titan III (34D)/Centaur), but without any payload propulsion changes. To capture the combined orbiter/ probe launch with the IUS (Case 5), not only requires the Δ-VEGA flight mode and a payload kick stage, but also reduces mission capability to only six satellite encounters.

Assuming an orderly SEPS procurement and development program the SEPS could be available in 1987. With the SEPS the IUS captures the baseline combined orbiter/probe launch and 11 satellite encounters using the Solar Electric with Earth gravity assist (SEEGA) flight mode (Case 6). The trip time is only a year longer but Jupiter arrival occurs more than three years after the 1985 baseline due to the 1987 launch.

TABLE 5.2-1

SUMMARY OF GALILEO MISSION ALTERNATIVES

CASE	JUPITER ARRIVAL	LAUNCH	PAYLOAD	SAT. ENCS	FLIGHT MODE	POST-STAGE PROPULSION	UPPER STAGE
1	MID-87	APR 85	ORBITER/ PROBE	11	DIRECT	NONE	WIDE-BODY CENTAUR
2	EARLY-90	JUL 87	ORBITER/ PROBE	11	DIRECT	NONE	IOTV
3	LATE-89	JUNE 86	PROBE (W/CARRIER)	-	DIRECT	P/L KICK STAGE	IUS
	LATE-89	AUG 85	ORBITER ONLY	11	ΔVEGA	P/L KICK STAGE	IUS
4	EARLY-90	AUG 85	ORBITER/ PROBE	11	ΔVEGA	NONE (L3-55)	ADV TRANSTAGE/ Δ3920 OR T34D/CENTAUR
5	EARLY-90	AUG 85	ORBITER/ PROBE	6	ΔVEGA	P/L KICK STAGE	IUS
6	LATE-90	JUL 87	ORBITER/ PROBE	11	SEEGA	SEPS	IUS

Significant upper stage impacts on Galileo mission can be summarized as follows:

1. Only the wide-body Centaur option preserves the present 1985 Galileo baseline mission.

2. All other stage options defer Galileo results by 2-3 years and substantially increase project cost.

3. Restricting stage capability to the IUS in 1985 requires additional post-stage propulsion development, more launches, and/or reduced mission objectives.

5.2.2.4 ISPM-ESA

Two mission alternatives for the International Solar Polar Flight Project (ISPM) are presented in Table 5.2-2, each assuming only the launch of the ESA spacecraft. Both assume a launch in May 1986. Case 1, the baseline, assumes a Centaur launch. Case 2 with the IUS is captured... provided a kick stage is incorporated into the ESA payload or integrated with the stage (e.g., IUS Star 48). The injection conditions for either alternative preserve near-polar transits of the Sun as required by baseline science objectives. Using the Advanced Transtage or wide-body Centaur would obviate the need for the kick stage.

TABLE 5.2-2

SUMMARY OF ISPM MISSION ALTERNATIVES

CASE	SOLAR POLE ARRIVED	LAUNCH	PAYLOAD	FLIGHT MODE	POST-STAGE PROPULSION	UPPER STAGE
1	LATE - 89	MAY 86	ESA S/C	JUPITER SWINGBY	P/L KICK	WIDE BODY CENTAUR
2	LATE - 90	JUN 87	ESA S/C	JUPITER SWINGBY	P/L KICK	WIDE BODY CENTAUR

5.2.2.5 VOIR

Three alternatives were assessed for the VOIR Flight Project, all launched during the 1988 opportunity. These are presented in Table 5.2-3. Case 1 assumes full chemical payload propulsion at Venus for capture to low circular orbit required for radar mapping of the planet's surface. An early Type II launch allows the mapping mission to begin by mid-1988. Only the wide-body Centaur or IOTV capture this alternative due to the large amount of payload propulsion which must be carried to Venus. Case 2 uses aerobraking in the upper Venus atmosphere to reduce orbit propulsion requirements and hence injected mass at Earth escape. A conservative aerobraking sequence ending in a 3-hour elliptical Venus orbit is used and forms the present baseline for this mission. A March 1988 Type 1 launch delivers the payload to the mapping orbit after aerobraking about two months later than the all-chemical option. At least the performance of the IUS Twin, an Advanced Transtage, or the Titan III (34D)/Centaur is required to capture this option. Case 3 is similar to Case 2 in that aerobraking is also used, but has been extended down to a final 2-hour Venus orbit. While this entails more risk and complexity of flight operations, it also reduces the chemical orbit propulsion requirement. The consequent injected mass reduction is sufficient for this alternative to be captured by the IUS provided there is a payload kick stage added to the spacecraft. The mapping mission is also delayed a few more weeks to allow for the added aero braking.

TABLE 5.2-3
SUMMARY OF VOIR MISSION ALTERNATIVES

CASE	LOW ORBIT ARRIVAL	LAUNCH	PAYLOAD	ORBIT REDUCTION MODE	POST-STAGE PROPULSION	UPPER STAGE
1	JUL 89	DEC 87	ORBITER	CHEMICAL		WIDE-BODY CENTAUR
2	SEP 89	MAR 89	ORBITER	AEROBRAKE (24/3)*		ADV TRANSTAGE/ Δ3920 OR T34D/CENTAUR
3	OCT 89	MAR 89	ORBITER	AEROBRAKE (24/2)*	P/L KICK	IUS

*INITIAL/FINAL ORBIT PERIODS, HOURS - MISSION REQUIREMENTS SHOWN AS A REGION WITH TOP OF REGION FOR 1 hour FINAL AND BOTTOM OF REGION FOR 2 hour FINAL

In summary, the baseline VOIR aerobraking mission provides ample payload margin for either a wide-body Centaur or IOTV launch. It is also captured by the Advanced Transtage or Titan III (34D)/Centaur. The all-chemical VOIR alternative, although captured by the wide-body Centaur (or IOTV), has little margin (5%) for spacecraft propulsion development growth or upper stage degradation. Consequently, aerobraking is incorporated in the baseline mission design. The extended aerobraking option is acceptable and allows the mission to be captured by the IUS Star 48 with adequate margin. A strong preference for wide-body Centaur capability exists to avoid a launch deficient capability as this project progresses.

5.2.2.6 Option Assessment

In addition to the basic Upper Stage capability, a number of options have been proposed and addressed in this study. This assessment considers the following options:

1. Advanced Transtage with Delta 3920 second stage

2. Wide-Body Centaur

3. Interim Orbital Transfer Vehicle (IOTV)

Each of these options is addressed with and without the addition of SEPS (Solar Electric Propulsion Stage) as needed to perform the "reference" mission set. In this set, mission numbered 4, 5 and 9 utilize the SEPS. The approach taken in assessing stage performance impacts on exploration was to first structure a program addressing all ten mission objectives around the preferred capability of the Wide-Body Centaur with SEPS augmentation. Then the missions within this program were redefined to accommodate the reduced capability/availability of the remaining options, including the IUS, and the resulting changes (or impacts) were evaluated to determine a comparative degree of degradation associated with each performance reduction.

Impacts were classified into six specific areas, which are as follows:

1. available launch opportunities (or availability to launch on schedule for near term missions,
2. number of launches to achieve the same objective,
3. payload margin,
4. extended trip time and/or more complex or extended mission operations
5. necessary hardware to be developed,
6. mission objectives accomplished.

Launch opportunities to most solar system targets occur with a frequency of at least once every two years. Launch frequency is impacted by two stage-related factors: 1) inadequate performance, and 2) availability of the upper stage. The result, or impact, on program planning is one of reduced flexibility since missions become constrained to specific launch opportunities. If the upper stage performance is substantially degraded (e.g. IUS vs. Wide-Body Centaur) it may also be necessary to split a larger high-energy mission into two smaller payloads thus doubling the number of launches, which results in the second impact given above. Every launch has an associated launch margin. Less capability means less launch margin even though it may not be necessary to split the payload or slip the launch date. Less launch margin will have a mission impact if payload growth during development exceeds available margin.

The fourth stage-related mission impact is longer trip time and/or more complex flight operations required to reach the objective. This impact is especially critical for outer planet missions where very long trip times can result from inadequate stage capability. Poor upper stage performance can also result in the need for additional payload hardware. This impact almost always occurs when a single payload has to be split into two launches. It also happens when a lower launch-energy trajectory must be used which requires more payload propulsion (e.g. Δ-VEGA deep space impulses) to reach the target. The final impact area given is the reduction of mission objectives. This is usually a last resort to solving upper stage performance deficiency, without losing the mission altogether. It means for example, eliminating an entry probe, reducing the number of asteroid targets or satellite encounters, or eliminating some of the science experiments to save weight.

For the upper stage impacts analysis, then, each of the six impact areas was examined for each mission objective in the "reference" mission set. This was done for each of seven alternative stage options compared to the Wide-Body Centaur with SEPS "baseline" case. Impacts were categorized into two levels:

1. Severe(S) - severe impact, schedule/Upper Stage availability or major performance degradation

2. Moderate(M) - possible impact or minor performance degradation

The assessment results are presented in Tables 5.2-4 through 5.2-12. Nine mission objectives are listed along the left-hand side of each table; the two Mars precursor objectives have been combined into one mission opportunity since the Wide-body Centaur is capable of launching both spacecraft at once. Note that three of the nine mission objectives use SEPS augmentations when it is available.

Table 5.2-4 displays the only launch vehicle alternative which satisfies all planetary program requirements...the Wide-Body Centaur with SEPS augmentation. There are no impact areas and consequently this can be used to establish the reference capability.

TABLE 5.2-4

ASSESSMENT OF SOLAR SYSTEM EXPLORATION MISSION IMPACTS

WIDE-BODY CENTAUR AND SEPS CAPABILITY

MISSION OBJECTIVES	MISSION IMPACTS					
	OPPORTUNITIES	NUMBER OF LAUNCHES	TRIP TIME AND OR OPERATION	MASS MARGIN	HARDWARE	OBJECTIVES
GALILEO (JUPITER ORBITER & PROBE)						
ISPM						
VOIR (AEROBRAKING)						
MULTIPLE ASTEROID RENDEZVOUS *						
URANUS & NEPTUNE FLYBYS & PROBES						
MARS POLAR ORBITER & MARS NETWORK						
COMET RENDEZVOUS *						
SATURN ORBITER WITH DUAL PROBES *						
MARS SAMPLE RETURN (AEROCAPTURE & PROP PROD)						

		Summary
S	SEVERE (S) - SEVERE IMPACT OR MAJOR PERF. DEGRADATION	0%
M	MODERATE (M) - POSSIBLE IMPACT OR MINOR PERF. DEGRADATION	0%
	NO IMPACT OR EQUIVALENT PERFORMANCE	100%

SUMMARY

* SEPS MISSIONS

Table 5.2-5 presents the impact results anticipated with development of the Wide-body Centaur without SEPS augmentation. Clearly, only the three SEPS "reference" missions are affected. In the order of increasing performance impact, these missions are Saturn orbiter/probes, comet rendezvous, and multiple asteroid rendezvous. The summary across the entire mission model shown at the bottom of the chart indicates that about 20% of the areas are adversely affected.

TABLE 5.2-5

ASSESSMENT OF SOLAR SYSTEM EXPLORATION MISSION IMPACTS

WIDE-BODY CENTAUR WITHOUT SEPS CAPABILITY COMPARED TO WIDE-BODY CENTAUR AND SEPS

MISSION OBJECTIVES	MISSION IMPACTS					
	OPPORTUNITIES	NUMBER OF LAUNCHES	TRIP TIME AND OR OPERATION	MASS MARGIN	HARDWARE	OBJECTIVES
GALILEO (JUPITER ORBITER & PROBE)						
ISPM						
VOIR (AEROBRAKING)						
MULTIPLE ASTEROID RENDEZVOUS	M	S	M	S	S	
URANUS & NEPTUNE FLYBYS & PROBES						
MARS POLAR ORBITER & MARS NETWORK						
COMET RENDEZVOUS	M		M	S	S	
SATURN ORBITER WITH DUAL PROBES			S		S	
MARS SAMPLE RETURN (AEROCAPTURE & PROP PROD)						

S	SEVERE (S) - SEVERE IMPACT OR MAJOR PERF. DEGRADATION	13%	SUMMARY
M	MODERATE (M) - POSSIBLE IMPACT OR MINOR PERF. DEGRADATION	7%	
	NO IMPACT OR EQUIVALENT PERFORMANCE	80%	

Table 5.2-6 presents the results anticipated with development of the IOTV and SEPS augmentation. Here the issue is not one of performance but rather availability. Severe impacts occur only on the first two missions, i.e. Galileo and ISPM. However, because the impacts cause launch opportunity delays not only would near-term costs grow, but any planned sequence of future objectives would, undoubtedly, also be effected.

Table 5.2-7 presents the impact results anticipated with development of the IOTV without SEPS augmentation. These results are basically the same as the Centaur without SEPS option except for the near-term Galileo and ISPM missions for which the IOTV would not be available. Viewed against the entire "reference" mission set, the degree of major impact for IOTV without SEPS is about 17% compared to only 4% when SEPS availability was assumed.

Table 5.2-8 presents the impact results anticipated with development of the Advanced Transtage with SEPS augmentation. Although considerably less severe than those caused by having only the IUS, severe impacts again occur in the first mission i.e. Galileo. The schedule impact to Galileo is classified as "M" since the overall assessment of schedule indicates a moderate risk of delivering the Advanced Transtage in time for the Galileo launch in 1985. Most of the longer-term mission impacts occur in the form of less mass margin

TABLE 5.2-6

ASSESSMENT OF SOLAR SYSTEM EXPLORATION MISSION IMPACTS

IOTV AND SEPS CAPABILITY COMPARED TO WIDE-BODY CENTAUR AND SEPS

MISSION OBJECTIVES	MISSION IMPACTS					
	OPPORTUNITIES	NUMBER OF LAUNCHES	TRIP TIME AND/OR OPERATION	MASS MARGIN	HARDWARE	OBJECTIVES
GALILEO (JUPITER ORBITER & PROBE)	S (SCHEDULE)					
ISPM	S (SCHEDULE)					
VOIR (AEROBRAKING)						
MULTIPLE ASTEROID RENDEZVOUS *						
URANUS & NEPTUNE FLYBYS & PROBES						
MARS POLAR ORBITER & MARS NETWORK						
COMET RENDEZVOUS *						
SATURN ORBITER WITH DUAL PROBES *						
MARS SAMPLE RETURN (AEROCAPTURE & PROP PROD)						

S	SEVERE (S) - SEVERE IMPACT OR MAJOR PERF. DEGRADATION	4%	SUMMARY
M	MODERATE (M) - POSSIBLE IMPACT OR MINOR PERF. DEGRADATION	0%	
	NO IMPACT OR EQUIVALENT PERFORMANCE	96%	

* SEPS MISSIONS

TABLE 5.2-7

ASSESSMENT OF SOLAR SYSTEM EXPLORATION MISSION IMPACTS

IOTV WITHOUT SEPS CAPABILITY COMPARED TO WIDE-BODY CENTAUR AND SEPS

MISSION OBJECTIVES	MISSION IMPACTS					
	OPPORTUNITIES	NUMBER OF LAUNCHES	TRIP TIME AND/OR OPERATION	MASS MARGIN	HARDWARE	OBJECTIVES
GALILEO (JUPITER ORBITER & PROBE)	S					
ISPM	S					
VOIR (AEROBRAKING)						
MULTIPLE ASTEROID RENDEZVOUS	M	S	M	S	S	
URANUS & NEPTUNE FLYBYS & PROBES						
MARS POLAR ORBITER & MARS NETWORK						
COMET RENDEZVOUS	M		M	S	S	
SATURN ORBITER WITH DUAL PROBES			S		S	
MARS SAMPLE RETURN (AEROCAPTURE & PROP PROD)						

S	SEVERE (S) - SEVERE IMPACT OR MAJOR PERF. DEGRADATION	17%	SUMMARY
M	MODERATE (M) - POSSIBLE IMPACT OR MINOR PERF. DEGRADATION	7%	
	NO IMPACT OR EQUIVALENT PERFORMANCE	76%	

which, although judged of intermediate concern, is not at all comforting considering the preliminary level of definition which exists for these objectives. The summary at the bottom of the chart indicates that about one-fifth of the areas are adversely affected, split evenly between the "Severe and Moderate" levels.

TABLE 5.2-8

ASSESSMENT OF SOLAR SYSTEM EXPLORATION MISSION IMPACTS

ADV TRANSTAGE AND SEPS CAPABILITY COMPARED TO WIDE-BODY CENTAUR AND SEPS

MISSION OBJECTIVES	MISSION IMPACTS					
	OPPOR-TUNITIES	NUMBER OF LAUNCHES	TRIP TIME AND/OR OPERATION	MASS MARGIN	HARDWARE	OBJECTIVES
GALILEO (JUPITER ORBITER & PROBE)	M (SCHEDULE)		S			
ISPM						
VOIR (AEROBRAKING)				M		
MULTIPLE ASTEROID RENDEZVOUS *				M		
URANUS & NEPTUNE FLYBYS & PROBES			S	S	S	
MARS POLAR ORBITER & MARS NETWORK				M		
COMET RENDEZVOUS *				M		
SATURN ORBITER WITH DUAL PROBES *			S			
MARS SAMPLE RETURN (AEROCAPTURE & PROP PROD)				M		

S SEVERE (S) - SEVERE IMPACT OR MAJOR PERF. DEGRADATION 10%
M MODERATE (M) - POSSIBLE IMPACT OR MINOR PERF. DEGRADATION 12%
NO IMPACT OR EQUIVALENT PERFORMANCE 80%
} SUMMARY

* SEPS MISSIONS

Table 5.2-9 presents the impact results anticipated with development of the Advanced Transtage without SEPS augmentation. Since this upper stage is considerably more capable than is the IUS, the adverse impact is not as severe but is still significant. Approximately 50% of the areas are unaffected relative to the "baseline" option. Severe impacts for the Advanced Transtage without SEPS has increased to 30% compared to only 14% when SEPS availability was assumed.

Table 5.2-10 presents the impact results of attempting the "reference" mission set with present IUS capability with SEPS augmentation. Every mission objective except ISPM has at least one severe impact with some having as many as four. Fewer than half of the impact areas examined are unaffected by the lower IUS performance capability compared to the Wide-Body Centaur. The impacts are particularly severe on near-term objectives, i.e. Galileo, where mission designs have already evolved to maturity assuming much better performance capability. The summary at the bottom of the chart indicates that 44% of possible impacts would be severe with another 20% being of moderate concern.

TABLE 5.2-9

ASSESSMENT OF SOLAR SYSTEM EXPLORATION MISSION IMPACTS
ADV TRANSTAGE WITHOUT SEPS CAPABILITY COMPARED TO WIDE-BODY CENTAUR AND SEPS

MISSION OBJECTIVES	MISSION IMPACTS					
	OPPOR-TUNITIES	NUMBER OF LAUNCHES	TRIP TIME AND/OR OPERATION	MASS MARGIN	HARDWARE	OBJECTIVES
GALILEO (JUPITER ORBITER & PROBE)	M (SCHEDULE)		S			
ISPM						
VOIR (AEROBRAKING)				M		
MULTIPLE ASTEROID RENDEZVOUS	S	S	M	S	S	M
URANUS & NEPTUNE FLYBYS & PROBES			S	S	S	
MARS POLAR ORBITER & MARS NETWORK				M		
COMET RENDEZVOUS	M		S	S	S	M
SATURN ORBITER WITH DUAL PROBES	S		S	M	S	
MARS SAMPLE RETURN (AEROCAPTURE & PROP PROD)				M		

S — SEVERE (S) - SEVERE IMPACT OR MAJOR PERF. DEGRADATION 30%
M — MODERATE (M) - POSSIBLE IMPACT OR MINOR PERF. DEGRADATION 19%
(blank) — NO IMPACT OR EQUIVALENT PERFORMANCE 51%
} SUMMARY

TABLE 5.2-10

ASSESSMENT OF SOLAR SYSTEM EXPLORATION MISSION IMPACTS
IUS AND SEPS CAPABILITY COMPARED TO WIDE-BODY CENTAUR AND SEPS

MISSION OBJECTIVES	MISSION IMPACTS					
	OPPOR-TUNITIES	NUMBER OF LAUNCHES	TRIP TIME AND/OR OPERATION	MASS MARGIN	HARDWARE	OBJECTIVES
GALILEO (JUPITER ORBITER & PROBE)	M (SCHEDULE)	S	S		S	M
ISPM			M	M	M	M
VOIR (AEROBRAKING)			M	S	M	
MULTIPLE ASTEROID RENDEZVOUS *	M			S		
URANUS & NEPTUNE FLYBYS & PROBES	S	S	S		S	
MARS POLAR ORBITER & MARS NETWORK	M	M		S		
COMET RENDEZVOUS *	S		S	S		
SATURN ORBITER WITH DUAL PROBES *	M	S	S	S	S	
MARS SAMPLE RETURN (AEROCAPTURE & PROP PROD)	S			S	S	

S — SEVERE (S) - SEVERE IMPACT OR MAJOR PERF. DEGRADATION 44%
M — MODERATE (M) - POSSIBLE IMPACT OR MINOR PERF. DEGRADATION 20%
(blank) — NO IMPACT OR EQUIVALENT PERFORMANCE 36%
} SUMMARY

* SEPS MISSIONS

Table 5.2-11 presents the impact results anticipated with the use of the present IUS capability without SEPS augmentation. This upper stage option is a very poor performer against the "reference" mission set. Fewer than 30% of the impact areas are unaffected compared to the Wide-body Centaur with SEPS "baseline". The degree of areas severely impacted by use of the IUS has increased from 39% (with SEPS) to 57% (without SEPS). In the case of the comet rendezvous, no possible mission has yet been identified. Due to purely energy considerations it is believed that no such mission exists.

TABLE 5.2-11

ASSESSMENT OF SOLAR SYSTEM EXPLORATION MISSION IMPACTS

IUS WITHOUT SEPS CAPABILITY COMPARED TO WIDE-BODY CENTAUR AND SEPS

MISSION OBJECTIVES	MISSION IMPACTS					
	OPPOR-TUNITIES	NUMBER OF LAUNCHES	TRIP TIME AND OR OPERATION	MASS MARGIN	HARDWARE	OBJECTIVES
GALILEO (JUPITER ORBITER & PROBE)	M (SCHEDULE)	S	S		S	M
ISPM			M	M	M	M
VOIR (AEROBRAKING)			M	S	M	
MULTIPLE ASTEROID RENDEZVOUS	S	S	S	S	S	S
URANUS & NEPTUNE FLYBYS & PROBES	S	S	S		S	
MARS POLAR ORBITER & MARS NETWORK	M	M		S		
COMET RENDEZVOUS ••	S	S	S	S	S	S
SATURN ORBITER WITH DUAL PROBES	S	S	S	S	S	M
MARS SAMPLE RETURN (AEROCAPTURE & PROP PROD)	S			S		

SUMMARY:

S	SEVERE (S) - SEVERE IMPACT OR MAJOR PERF. DEGRADATION	57%
M	MODERATE (M) - POSSIBLE IMPACT OR MINOR PERF. DEGRADATION	20%
	NO IMPACT OR EQUIVALENT PERFORMANCE	23%

•• NO MISSION

A summary matrix of all these impact results is presented in Table 5.2-12. Here the "reference" mission objectives have been combined into two categories: 1) near-term program, and (2) future program. Each of the four upper stage candidates are listed across the top of the matrix. Comparative ratings are given both with and without SEPS augmentation. Recall that the "baseline" case for this comparison is the Wide-body Centaur with SEPS augmentation. Combinations of program category and upper stage option with no impact are obviously acceptable. Those rated "Severe" are unacceptable for the reasons outlined above. Those rated "Moderate" might be acceptable, depending upon more specific development of future exploration plans. Only the Wide-body Centaur is acceptable to the near-term plan which consists of Galileo, ISPM and VOIR missions. Only the Wide-body Centaur and IOTV provide the necessary performance capability in the future program objectives to assure adequate flexibility and resilence for sensible planning.

TABLE 5.2-12

SUMMARY

UPPER STAGE ASSESSMENT FOR SOLAR SYSTEM EXPLORATION

PROGRAM OBJECTIVE	UPPER STAGE ALTERNATIVE (WITH SEPS / WITHOUT SEPS)			
	WIDE-BODY CENTAUR	IOTV	ADVANCED TRANSTAGE	IUS (II)
NEAR TERM MISSIONS	/	(SCHEDULE) S / S (SCHEDULE)	S / S	S / S
FUTURE MISSIONS	/ M	/ M	M / S	S / S

S	SEVERE (S) - SEVERE IMPACT OR MAJOR PERF. DEGRADATION
M	MODERATE (M) - POSSIBLE IMPACT OR MINOR PERF. DEGRADATION
	NO IMPACT OR EQUIVALENT PERFORMANCE

5.3 DOD ASSESSMENT

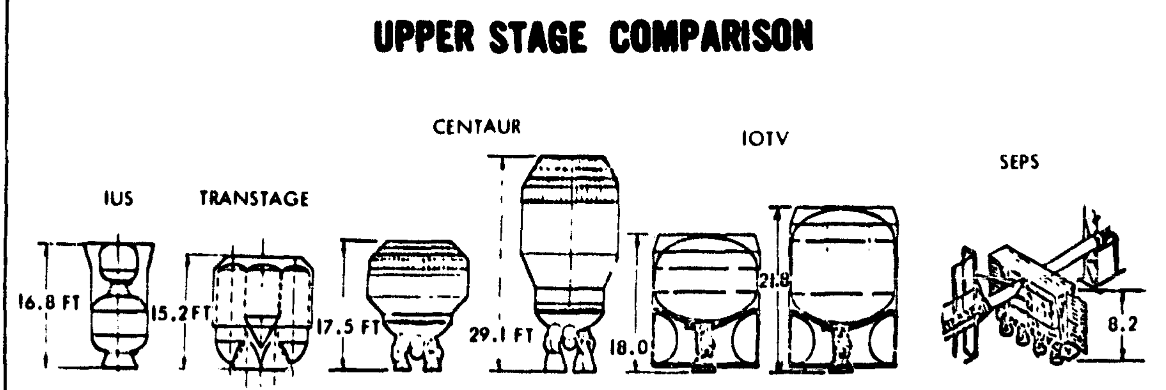
5.3.1 INTRODUCTION

We will measure each system concept, as proposed, against the requirements that were outlined and discussed in the previous section. This will be a qualitative assessment and consequently somewhat less rigorous than would be done in a formal system validation process. The IUS and Centaur data is available in considerable depth in formal contractual documentation; however, most of the other system concepts presented are available only in a briefing format. Consequently, considerable judgement must be applied as to the degree that each system concept meets each specific requirement. Most concepts, as proposed, are based on a relatively simple, minimum modification approach to putting an upper stage in the Shuttle. This, in fact, closely parallels concepts previously considered and rejected by the Air Force as not adequate for meeting DOD upper stage requirements in the Space Shuttle era.

5.3.2 SYSTEMS EVALUATED

We have evaluated a range of upper stages as proposed by a number of different contractors. Those assessed here are representative of the systems potentially available. Several contractors have presented concepts that are not specifically addressed in this report; while there are some differences in approach, there were no fundamentally different concepts presented. We do believe, therefore, that there is a sufficient number of upper stage concepts to preclude the possibility that significant changes in the final conclusions would result by the addition of another candidate. The stages included in this assessment are illustrated in Figure 5.3-1.

FIGURE 5.3-1



Inertial Upper Stage (IUS) Two-Stage configuration. Manufacturer - Boeing Aerospace Corporation. The IUS is a solid rocket motor propelled vehicle with one large and one small rocket motor. The IUS is currently being developed to meet defense and NASA earth orbiting mission requirements. The IUS has redundant systems in order to maximize the probability of launch success.

Wide-Bodied Centaur. Manufacturer - General Dynamics Corporation. This is a derivative of the expendable launch vehicle version of the Centaur which is a cryogenic (liquid oxygen, liquid hydrogen) upper stage. Cryogenic propellants approach the theoretical limits of efficiency for chemical propulsion systems. NASA has begun development of the wide-bodied Centaur (29' long version) for use on planetary missions in the Shuttle.

STS Transtage. Manufacturer - Martin Marietta Corporation. The STS Transtage is an adaption of the existing Titan Transtage for Shuttle use. It employs storable hypergolic propellants. The Transtage is representative of the storable propellant upper stage concepts; it is also the most mature of these concepts.

Interim Orbital Transfer Vehicle (IOTV) or Optimized Cryogenic Upper Stage. Manufacturer - to be determined by competition. An optimized family of cryogenic stages would be built from the beginning to accommodate the full range of NASA and defense requirements. Program costs estimates are based on this intent and include high launch reliability and various length stages, as well as the other operational defense requirements.

Solar Electric Propulsion System (SEPS). The conceptual SEPS can supplement the chemical propulsion stages and is capable of moving large or heavy satellites to earth orbits with low, but continuous, acceleration. Very long transit times are required (month versus hours for chemical stages).

5.3.3 EVALUATION METHODOLOGY

Each Upper Stage has received a qualitative assessment of its ability, as presently conceived, to meet each of the stated defense mission requirements. The evaluation of each upper stage was first done against the operational DOD payload requirements and then against the requirements for the potential post-1990 DOD missions. In each case, a detailed evaluation was performed against each of the requirements shown in Figures 4.2-2 and 4.2-3. This detailed assessment was then summarized as shown in Figures 5.3-2 and 5.3-3; this summary provides a more balanced assessment since not all requirements are of equal importance. This assessment is conducted and presented on a qualitative basis with the results presented in a satisfactory/unsatisfactory code. The meaning of each code is outlined below:

Unsatisfactory (U): Upper stage concept as presented clearly does not meet the specified requirement, and would be extremely difficult or impossible to fix to satisfy the requirement.

Satisfactory with Modifications (S/M): Concept does not meet the requirement, but the system concept can be modified to satisfy the requirement at some cost; or the concept is sufficiently undefined so that a significant uncertainty exists in the system capability.

Satisfactory (S): System concept as presented meets the requirement.

We will discuss the significant deviations from the operational DOD payload requirements as presented and then provide a brief assessment of the long term growth potential of each stage against the potential post-1990 DOD missions.

FIGURE 5.3-2
DOD STS UPPER STAGE REQUIREMENTS SATISFACTION FOR OPERATIONAL DOD PAYLOADS

REQUIREMENTS	FIRM REQUIREMENT	INERTIAL UPPER STAGE (IUS)		WIDE BODY CENTAUR		STS TRANSTAGE		TOTV (CRYOGENIC)		REMARKS
		DEGREE SATISFY RQMT*		DEGREE SATISFY RQMT		DEGREE SATISFY RQMT		DEGREE SATISFY RQMT		
PERFORMANCE										
Payload Weight	5,500 lbs (geo)	S/M		S		S		S		
Injection Accuracy	All Factors	S		S/M		S/M		S		
OPERATIONAL										
Max Launch Reliability	96%	S		S/M		S/M		S		
Guidance Related	All factors	S		S/M		S/M		S		
Load Alleviation	Yes - Soft Mnt Cradle	S		S/M		S/M		S		
Orbiter Pay Loiter	Up to 7 Days	S		S/M		S		S		
Payload Length	42 Ft	S		S/M		S		S		
Other S/C Support	All Factors	S		S/M		S		S		

*Unsatisfactory - U - Does not meet requirement; extremely difficult or impossible to fix. N/A - Not applicable
Satisfactory with Modifications - S/M - Requires Modifications to meet requirements.
Satisfactory - S - Meets requirement completely.

5.3.4 UPPER STAGE ASSESSMENT VERSUS OPERATIONAL DOD PAYLOAD REQUIREMENTS

We will briefly summarize each stage against its technical requirements as shown in Section 4.2 of this report, with particular emphasis on those items where the requirements are not fully met. The detailed results of our assessment of each stage against operational DOD payload requirements are shown in Figure 5.3-2. A word of caution - these assessments are not absolute, they represent a relative measure against DOD requirements. Additional funding can reduce or eliminate some of the deficiencies cited; in fact, any of the candidate systems evaluated can meet the full range of operational requirements with adequate funding.

FIGURE 5.3-3

DOD STS UPPER STAGE REQUIREMENTS SATISFACTION FOR POTENTIAL POST - 1990 DOD MISSIONS

REQUIREMENTS	ESTIMATED REQUIREMENT	INERTIAL UPPER STAGE (IUS)		WIDE BODY CENTAUR		STS TRANSTAGE		TOTV (CRYOGENIC)		REMARKS
		DEGREE SATISFY RQMT*		DEGREE SATISFY RQMT		DEGREE SATISFY RQMT		DEGREE SATISFY RQMT		
PERFORMANCE										
Payload Weight	30,000+lbs (geo/equiv)	U		S/M		U		S/M		SEPS + CRYO + Shuttle upgrades needed for some missions
Injection Accuracy	All Factors	S		S/M		S/M		S		
OPERATIONAL										
Max Launch Reliability	96%	S		S/M		S/M		S		
Guidance Related	All Factors	S		S/M		S/M		S		
Load Alleviation	Yes - Soft Mnt Cradle	S		S/M		S/M		S		
Orbiter Bay Loiter	Up to 7 Days	S		S/M		S		S		
Payload Length	Full Bay	U		S/M		U		S		P/L & upper stage mate on orbit
Other S/C Support	All Factors	U		S/M		S/M		S/M		

*Unsatisfactory - U - Does not meet requirement; extremely difficult or impossible to fix. N/A - Not applicable
Satisfactory with Modifications - S/M - Requires Modifications to meet requirements.
Satisfactory - S - Meets requirement completely.

Inertial Upper Stage.

The IUS, as designed, meets all approved program (Figure 4.2-2, Column 1) current DOD launch requirements (5,000 pounds to a geosynchronous orbit).

The IUS will meet all firm planned (Figure 4.2-2, Column 2) payload launch requirements projected through the 1980's with one exception. Moderate growth to a 5,500 pound payload weight will be required; this change can be accommodated through a relatively low risk propulsion upgrade. Sufficient lead time is available so this upgrade can be routinely accomplished. The 5,500 pound capability can be obtained by a non recurring investment of about $50M to $60M.

The IUS can grow to about a 6,000-6,500 pound geosynchronous orbit capability by continuing the propulsion upgrade mentioned above. This capability can be obtained for a total non recurring investment of about $130M to $140M (an increment of $80 million above the 5,500 pound capability in the previous paragraph). This would meet the desired capability (Figure 4.2-2, Column 3) stated by the operational DOD payload programs (5,800 pounds in 1987, 6,200 pounds in 1988) until a major payload block change occurs (projected as 8,000 pounds in 1990). However, the 6,000+ pounds represents the limits of low to moderate technical risk IUS growth; the 8,000 pound capability could only be obtained through a higher risk propulsion upgrade.

IUS growth potential over the long term is severely limited. While the IUS can still continue to support a number of missions through the 1990's, a new stage will likely be required to accommodate major DOD spacecraft block changes and new missions in the late 1990's and early in the 21st Century.

Wide-Bodied Centaur (29 Foot Version).

The wide-bodied Centaur meets, and indeed greatly exceeds, all projected firm defense requirements for throw weight through the 1980's and into the mid-1990's.

Considerable effort, above the planned NASA baseline, would be required to satisfy the full range of defense mission requirements. This results from the minimum modification approach currently planned to utilize the Centaur in the Shuttle. However, depending upon which defense payloads transition to the Centaur, only a portion of these requirements may need to be satisfied at any given point in time. Reliability and guidance system improvements are closely related; incorporating redundant avionics with current technology (probably by adapting the IUS avionics) would eliminate the deficiencies in reliability and guidance and improve the injection accuracy. A structural modification (including qualification of the RL10 engine to run on a 6:1 mixture ratio) will enable the Centaur to accommodate 42 foot payloads. A load alleviation system can be designed and qualified which will enable the DOD spacecraft to survive the peak Shuttle landing loads. Several other modifications can be made (additional spacecraft services; insulation of the tanks, etc) which will improve the ability to accommodate the range of defense mission requirements. These changes could be retrofitted into the basic Centaur for between $250M and $275M, and this work could be accomplished downstream as needed to support those spacecraft which choose to transition to the Centaur.

STS Transtage.

The proposed Transtage configuration can meet all known firm and projected DOD payload weight requirements through the 1980's and into the early 1990's.

Additional effort, above the contractor proposed baseline, would be required to meet all defense requirements. Since the Transtage is considered as a replacement (vice supplement) to the IUS all the requirements would need to be satisfied. As with the Centaur, adapting the redundant avionics from the IUS would significantly improve system reliability and guidance flexibility and accuracy. A load alleviation system can be designed to enable the Transtage to absorb the Shuttle landing loads and prevent spacecraft damage. Only relatively minor changes would be needed in other system areas to fully accommodate defense mission needs (the Transtage has been launching defense spacecraft on the expendable Titan IIIC). Consequently, the Transtage changes could be made for between $100M and $125M.

Interim Orbital Transfer Vehicle (IOTV)/Optimized Cryogenic Upper Stage.

This stage could meet all current and projected defense requirements through the 1980's and into the early 1990's. This new optimized Stage has the greatest long term growth potential since it can make maximum utilization of the Space Shuttle bay and could be built to meet the full range of defense mission requirements.

5.3.5 UPPER STAGE ASSESSMENT VERSUS POTENTIAL POST-1990 DOD MISSION REQUIREMENTS

The operational DOD payloads discussed in the previous section will probably continue (in larger and more capable configurations) indefinitely. However, some new mission concepts are likely to be added late in this century. Selected concepts were presented in Figure 4.2-3 in terms of their upper stage requirements. These new concepts will place even greater demands on all aspects of space transportation including the upper stage. Figure 5.3-3 presents an estimate of long term requirements based on these post-1990 missions; each upper stage is then assessed against these requirements. There are some very significant changes in the results when compared with operational DOD payloads.

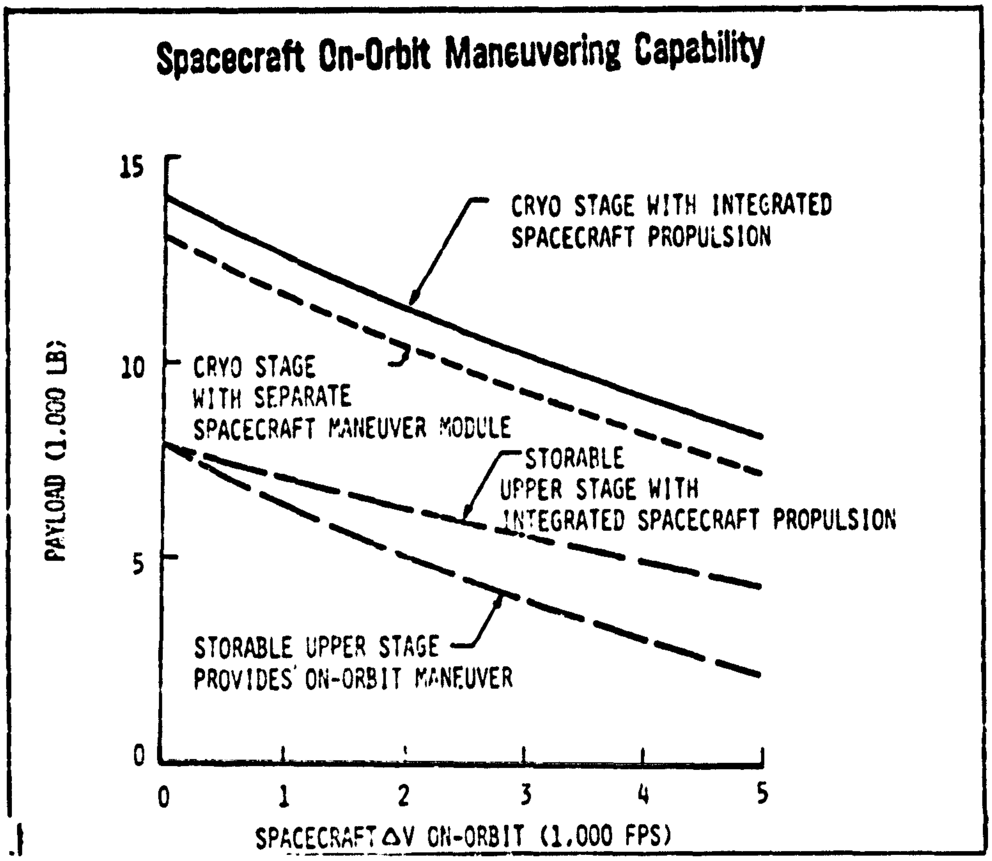
Inertial Upper Stage (IUS).

The IUS payload capability falls far short of meeting the more demanding of these missions, and Shuttle throw weight limits will be reached at about 9-10,000 pounds of geosynchronous payload. Shuttle weight limits will also constrain IUS use in an on-orbit rendezvous mode with large (full bay) payloads. Further, the new demands of spacecraft recovery, multiple engine burns, and multiple rendezvous cannot be reasonably attained by a solid-propellant stage. Long term IUS use will be limited to deployment of payloads similar to those planned for the 1980's.

Wide-Bodied Centaur (29 Foot Version).

The Centaur shows a considerable capability against these long term requirements, although significant modifications would be needed to fully satisfy the projected needs. However, even the Centaur (and the IOTV) cannot handle the largest projected payloads (equivalent to 30,000 pounds in geosynchronous orbit) without added propulsion capability such as the Solar Electric Propulsion System (SEPS).

FIGURE 5.3-4



STS Transtage.

The Transtage is also limited on maximum payload (at about 9,000 to 10,000 pounds) to geosynchronous orbit due to the Shuttle throw weight limitations. Even its ability to handle long-term, on-orbit storage is of limited value; Figure 5.3-4 shows that the cryogenic stages can provide greater on-orbit maneuver capability by transporting a storable propellant maneuver module (either separate or integrated with the spacecraft) to the storage orbit.

Interim Orbital Transfer Vehicle (IOTV)

The IOTV shows a greater capability against these potential post-1990 DOD mission requirements than any other upper stage. However, as with the Centaur, an added propulsive capability, like the SEPS, will be needed for the most demanding missions.

5.3.6 OTHER CONSIDERATIONS

It is apparent that the requirements of 21st century defense space missions go well beyond the level which can be satisfied completely with higher energy upper stages (even those in the Centaur/IOTV class), particularly if they must operate within a Shuttle which is performance limited to 65,000 pounds. Consequently, we should

begin to assess methods of increasing Shuttle payload capability, evaluate follow-on launch systems with payload capabilities well beyond the Shuttle, investigate the benefits of using multiple Shuttle flights with on-orbit renedezvous of the upper stage and payload, and consider the use of performance techniques like Solar Electric Propulsion.

Further, as the survivability of space systems becomes increasingly important to our national defense, higher energy will likely be required for all aspects of space transportation. Survivability requirements could result in heavier spacecraft and, eventually, in the need to conduct high altitude launches from Vandenberg AFB in the case of outage at the Kennedy Space Center. This will drive both greater Shuttle performance (to lift the combined spacecraft and upper stage) and increased upper stage performance (to handle the greater plane change needed to achieve geosynchronous orbit from a Vandenberg launch). These factors will also drive future upper stages toward the more efficient cryogenic propellant vehicles.

SECTION

6.0

UPPER STAGE OPTIONS - COST AND SCHEDULE CONSIDERATIONS

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6.0 UPPER STAGE OPTIONS - COST AND SCHEDULE CONSIDERATIONS

6.1 INTRODUCTION

6.2 LIFE CYCLE COST ANALYSIS

6.2.1 INTRODUCTION

Schedule considerations are an important factor in near term decisions regarding upper stage availability for critical defense missions. During the process of preparing the life cycle cost analysis to be discussed in a later paragraph, several schedule related assumptions were made: they included: first, a 1 Oct 81 upper stage decision; NASA funding, as required, available on 1 Oct 81; DOD funding for new starts or production available 1 Oct 82. This establishes the earliest availability of Shuttle upper stages. The availability of these stages is illustrated in Figure 6.2-1. As a part of the life cycle cost analysis, each stage within each option was assessed for its ability to capture some element of the mission model and thus ensure that all payload requirements could be met. The following paragraphs discuss the options investigated and illustrate the resulting mission "capture" for each stage.

FIGURE 6.2-I

EARLIEST UPPER STAGE AVAILABILITY

STAGE	CALENDAR YEAR 82	83	84	85	86	87
T34D/TRANSTAGE	▲					
T34D/IUS	▲					
T34D/CENTAUR			▲			
STS IUS						
2 STAGE BASIC	▲					
2 STAGE GROWTH (6,000+ LB GEO)					▲	
TWIN STAGE				▲		
STS/CENTAUR						
29 FT				▲*	**▲	
18 FT					**▲	
STS/TRANSTAGE				▲*	**▲	
STS/SEPS						▲
STS/IOTV						▲

* EXISTING AVIONICS ** IUS CLASS (REDUNDANT/INCREASED RELIABILITY) AVIONICS

6.2.2 OPTIONS

A number of possible options were developed in order to assess the capability of each stage to support particular elements of the mission model. The life cycle launch cost was evaluated for each of these options. The options are defined in Figure 6.2-2 and include various mixes of IUS, modified Centaur, an optimized cryogenic vehicle known as the Interim Orbital Transfer Vehicle (IOTV), and Transtage. An option employing the Solar Electric Propulsion System (SEPS) was also considered. One conclusion emerges from evaluation of the schedule availability; the procurement of the first 13 Inertial Upper Stage vehicles is necessary in order to support near term NASA and defense earth orbiting launch requirements. However, the IUS schedule is extremely tight if additional IUS vehicles should be required to support a 1985 planetary flight.

FIGURE 6.2-2

NASA/DOD UPPER STAGE OPTIONS FOR LIFE CYCLE COST ANALYSIS

•	1	2 STAGE IUS (1982), TWIN IUS (1985) SPACECRAFT KICK STAGE (ISPM)
	2	2 STAGE IUS (1982), 29 FT WIDE BODY CENTAUR (1985)
•	3A	2 STAGE IUS (1982), T34D/CENTAUR (1985), IOTV (1987)
	3B	2 STAGE IUS (1982), SPACECRAFT KICK STAGE (ISPM) IOTV (1987)
	3C	2 STAGE IUS (1982) IOTV (1987)
	4A	2 STAGE IUS (1982) THRU FIRST PRODUCTION BUY (4), WIDE BODY CENTAUR - 29 FT (1985) AND 18 FT (1987)
	4B	4A PLUS CENTAUR WITH ALL DOD MODIFICATIONS (1987)
•	5A	2 STAGE IUS (1982) THRU FIRST PRODUCTION BUY (4), STS TRANSTAGE (1985)
•	5B	5A PLUS TRANSTAGE WITH ALL DOD MODIFICATIONS (1987)
	6	2 STAGE IUS (1982), SPACECRAFT KICK STAGE (ISMP & VOIR), SEPS (1987)
•	7	2 STAGE IUS (1982), KICK STAGE (GALILEO (2), VOIR & ISPM)

• REQUIRES SPLIT MISSIONS AND/OR INDIRECT TRAJECTORIES FOR PLANETARY MISSIONS

6.2.3 MISSION MODEL

The specific mission model for each option is shown in Figure 6.2-3; it shows the number and types of missions (both civil and defense) "captured" by each upper stage. For example, in Option 1, 78 total flights are projected through 1994 with 58 of these flights being NASA or DOD upper stage missions. The remaining missions are

civil commercial spacecraft. The total number of flights varies somewhat from one option to another because of payload mixing which is possible in certain cases due to the larger throw weight capability of the cryogenic stages.

FIGURE 6.2-3

TRAFFIC SUMMARY FOR LIFE CYCLE CYCLE COST ANALYSIS

AGENCY/VEHICLE	OPTION 1	2	3A	3B	3C	4A	4B	5A	5B	6	7
DOD											
T34D/TRANSTAGE	2	2	2	2	2	2	2	2	2	2	2
T34D/IUS	4	4	4	4	4	4	4	4	4	4	4
STS/IUS											
BASIC	29	29	29	29	29	3	3	3	3	29	29
GROWTH	12	12	12	12	12					12	12
STS/CENTAUR											
29 FT						26	26				
18 FT						12	12				
STS/TRANSTAGE								38	38		
NON-DOD (TOTAL CIVIL*/NASA)											
T34D/CENTAUR			2/2								
STS/IUS											
2 STAGE	26/6	6/6	10/6	11/7	7/6	6/6	6/6	6/6	6/6	30/10	32/12
TWIN	5/5										
2 STAGE + SEPS										1/1	
STS/CENTAUR		21/5				20/5	20/5				
STS/TRANSTAGE											
BASIC								22/2	22/2		
3920 2ND STAGE								5/3	5/3		
STS/IOIV			16/3	17/4	20/5						
TOTAL (NATIONAL**/DOD + NASA)	78/58	74/58	75/58	75/58	74/58	73/58	73/58	78/58	78/58	78/58	79/59

* INCLUDES COMMERCIAL SPACECRAFT ** INCLUDES COMMERCIAL + DOD + NASA SPACECRAFT

6.2.4 LIFE CYCLE COST ASSESSMENT

This analysis was performed based upon the schedule assumptions of Figure 6.2-1, the options of Figure 6.2-2, and the mission capture of Figure 6.2-3. We then developed a data base containing the major cost elements for each upper stage.

Several significant assumptions and ground rules form the basis for costs used in this analysis.

Cost data was obtained from the responsible government office (i.e. NASA/Lewis for Centaur, AF Space Division for IUS, etc).

All costs include a 20 per cent contingency factor--this may differ from the contingencies used in budgeting by both agencies.

Only costs subsequent to 1 October 1981 are used in the analysis; therefore, all prior "sunk" costs are excluded since FY 81 and prior year costs are the same for all options.

Transportation costs (upper stage, Shuttle, expendable launch vehicles) are the focus of this analysis, although an attempt was made to assess the spacecraft and nonrecurring integration costs when a different upper stage is used. Modifications to NASA planetary spacecraft are included; modification to DOD spacecraft are assumed "zero" and excluded since there was not sufficient time to evaluate this area in sufficient depth to make reliable estimates. All other spacecraft program costs are excluded.

Commercial users of upper stages are included in the non-DOD traffic. This adds 20 commercial spacecraft to the traffic model and influences the upper stage build rate (and thus the unit cost). However, only government costs are included in the life cycle cost results. This also has the effect of causing the study results to differ from agency budgets since we do not consider any potential "savings" (which result from reduced unit costs from larger buys) from upper stage purchases by commercial customers when planning DOD and NASA budgets.

IUS modifications to increase payload weight capability above 6000 pounds are included in all options where IUS is continued indefinitely. Further the IUS cost-to-complete includes all near term inputs resulting from development contract cost growth and the NASA termination of the planetary IUS variants. Out-year production cost estimates are developed on the same idealized ground rules used for the other upper stages (steady state production, no production breaks, etc).

All costs are in constant FY 81 dollars.

FIGURE 6.2-4
LIFE CYCLE COST COMPARISON (MILLIONS OF FY81 DOLLARS)

AGENCY/VEHICLE	OPTION										
	1	2	3A	3B	3C	4A	4B	5A	5B	6	7
NON-RECURRING	(960)	(1203)	(1551)	(1499)	(1480)	(1253)	(1373)	(1158)	(1343)	(931)	(994)
IUS	487	412	412	412	412	277	277	277	277	437	437
CENTAUR	-	460	-	-	-	605	725	-	-	-	-
TRANSTAGE	-	-	-	-	-	-	-	425	610	-	-
SEPS	300	300	300	300	300	300	300	300	300	300	300
IOTV	-	-	680	680	680	-	-	-	-	-	-
T34D/CENTAUR	-	-	50	-	-	-	-	-	-	-	-
PAYLOAD	173	31	109	107	88	71	71	156	156	194	257
RECURRING	(2984)	(3014)	(3018)	(2934)	(3013)	(2782)	(3028)	(2921)	(3167)	(3038)	(3053)
UPPER STAGE	1424	1454	1365	1374	1453	1222	1468	1361	1607	1478	1463
SHUTTLE	1560	1560	1500	1560	1560	1560	1560	1560	1560	1560	1590
T34D	-	-	153	-	-	-	-	-	-	-	-
TOTAL	3944	4217	4569	4433	4493	4035	4401	4079	4510	3969	4047
DELTA	-273	-	+352	+216	+276	-182	+184	-138	+293	-248	-170

The results of this analysis are shown in Figure 6.2-4. Option 2 (with the DOD using the IUS and NASA using the Centaur) is the study baseline, and option costs are measured relative to Option 2. Several general conclusions can be reached from this analysis.

Life cycle cost is not a driving decision factor. The variations between options are within the error inherent in the analysis. All options fall within ± 8% of the baseline program (Option 2).

General cost tendencies offer few surprises -- the cost of IUS-dominant alternatives are generally lower since much of the development costs are behind us; the cost of IOTV options are generally higher since the entire development is ahead of us; and the costs of DOD reliability modifications (Options 4B and 5B) tend to be higher than the corresponding "simple" systems because reliability effects are not considered. However, when the value of the spacecraft that would be saved due to increased reliability are considered, the reliability investments are repaid in every case; this is because the value of the first mission saved ($200M - $400M) equals the entire life cycle cost of the reliability upgrade.

Since the life cycle cost does not dominate the decision, near term investment strategies become important factors. NASA and DOD near term earth orbital requirements can only be satisfied by the IUS, so there is no significant near term DOD funding issue arising from this analysis. NASA funding strategy questions -- due to thei early (1985) planetary launch requirements -- are much more significant and will be addressed in the following section.

6.3 PLANETARY MISSION COST ANALYSIS RESULTS

The analysis performed took into consideration all aspects of costs, i.e., the development cost of upper stages, development and modification costs of launch complexes, modification cost to Orbiter, delta costs associated with the spacecraft configurations based on carrier vehicle requirements, cost of carrier vehicles, operations cost (ground and flight), etc. The options analyzed are shown in Figure 6.3-1.

The results are shown in Table 6.3-1 in real year dollars.

The nine options divide, by cost, roughly into three groups. Options 1, 2, 4 and 7 range in total cost from $1992M to $2161M. Options 5 and 6 cost from $2312M to $2381M. Options 3A, 3B and 3C cost from $2611M to $2740M. Options 3A, 3B and 3C cost the least in FY 1982 and FY 1983 but cost the most in runout since the development cost of the IOTV is deferred past 1983.

Options 1 and 7 in the first group use only the two stage or twin stage IUS plus kick stages. They offer competitive costs to Options 2 and 4 in 1982 and about $100M less cost in 1983. Options 2 and 4 utilize the Centaur STS and are thus capable of flying the missions in the most effective manner.

FIGURE 6.3-1

OPTIONS	LAUNCH ELEMENTS	LAUNCH ALTERNATIVES FOR PLANETARY PROGRAMS			
		1985	1986	1987	1988
1	TWO-STAGE IUS TWIN-STAGE IUS P/L KICK STAGES	GALILEO(COMB) TWIN-STAGE IUS (▲ VEGA)	ISPM (ESA) TWIN-STAGE IUS P/L KICK		VOIR (AB) TWIN-STAGE IUS
2	TWO-STAGE IUS WIDE-BODY CENTAUR	GALILEO(COMB) WIDE-BODY CENTAUR	ISPM (ESA) WIDE-BODY CENTAUR		VOIR (CH) WIDE-BODY CENTAUR
3A	TWO-STAGE IUS T34D/CENTAUR IOTV	GALILEO(COMB) T34D/CENTAUR (EGA)	ISPM (ESA) T34D/CENTAUR		VOIR (CH) IOTV
3B	TWO-STAGE IUS IOTV P/L KICK STAGE		ISPM (ESA) TWO-STAGE IUS P/L KICK	GALILEO(COMB) IOTV	VOIR (CH) IOTV
3C	TWO-STAGE IUS			GALILEO(COMB) IOTV	VOIR (CH) IOTV
	IOTV			ISPM (ESA) IOTV	
4	TWO-STAGE IUS WIDE-BODY CENTAUR SHORT W/B CENTAUR	GALILEO(COMB) WIDE-BODY CENTAUR	ISPM (ESA) WIDE-BODY CENTAUR		VOIR (CH) WIDE-BODY CENTAUR
5	TWO-STAGE IUS ADV TRANSTAGE ▲3920 2ND STAGE	GALILEO(COMB) ADV TRANSTAGE ▲3920 2ND STAGE(EGA)	ISPM (ESA) ADV TRANSTAGE ▲3920 2ND STAGE		VOIR (AB) ADV TRANSTAGE ▲3920 2ND STAGE
6	TWO-STAGE IUS SEPS P/L KICK STAGE		ISPM (ESA) TWO-STAGE IUS P/L KICK	GALILEO(COMB) TWO-STAGE IUS SEPS	VOIR (AB) TWO-STAGE IUS P/L KICK
7	TWO-STAGE IUS	GALILEO(ORB) TWO-STAGE IUS P/L KICK (▲ VEGA)	GALILEO(PROBE) TWO-STAGE IUS P/L KICK		VOIR (AB) TWO-STAGE IUS P/L KICK
	P/L KICK STAGES		ISPM (ESA) TWO-STAGE IUS P/L KICK		

Options 5 and 6 call for development of advanced Transtage plus the Delta 3920 stage and the early development of SEPS, respectively. In addition to adding cost to the planetary programs, these options create more complex missions, degrade mission performance, and have limited growth potential. The Transtage from a planetary mission point of view, considering cost and performance, is not a good option.

Options 3A, 3B and 3C all assume development of an IOTV. From a total cost picture, these options are the highest in cost. With the current requirements the possible advantages of an IOTV does not appear to justify the additional cost and development.

A specific cost analysis was also performed as related only to the Galileo mission as flown on either the Centaur STS or the IUS Two-Stage. The IUS Two-Stage option was associated with a split mission approach, with the Orbiter launch in 1985 and the Probe in 1986. Results indicate that some near term savings, small dollars can be realized but that at final completion with the Centaur approach, for less dollars (Centaur $1217.0M vs IUS $1279.7M), the U.S. gains a high energy stage in the U.S. STS stable. With the IUS's no new benefits are realized. In addition, the Centaur provides a direct trajectory, combined spacecraft, mission with less trip time and other positive benefits.

TABLE 6.3-I
COST OF LAUNCH ALTERNATIVES FOR PLANETARY PROGRAMS

		A	B	C	D	E	F	G	H	I
	COST ELEMENTS	OPTIONS								
		1	2	3A	3B	3C	4	5	6	7
1	STS/IUS-TRANSTAGE	403.9	-	-	60.0	-	-	683.7	700.0*	376.8
2	STS/CENTAUR-IOTV	-	538.0	861.0	889.0	977.0	538.0	-	-	
3	TITAN III/CENTAUR	-	-	334.8	-	-	-	-	-	-
4	STS FLIGHTS	222.0	222.0	86.2	235.7	262.8	222.0	222.0	235.7	293.2
5	GALILEO	611.0	417.0	567.0	531.0	531.0	417.0	567.0	672.0	718.0
6	SOLAR POLAR	75.3	50.3	50.3	75.3	56.3	50.3	50.3	75.3	75.3
7	VOIR	680.0	680.0	680.0	680.0	680.0	680.0	680.0	698.0	698.0
8	ORBITER/KSC	-	124.0	161.0	140.0	140.0	124.0	109.1	-	-
9	TOTAL	1992.2	2031.3	2740.3	2611.0	2627.1	2031.3	2312.1	2381.0	2161.3
10	FY 1982	209.8	243.0	145.2	136.5	126.0	243.0	290.6	169.9	215.5
11	FY 1983	232.3	337.4	193.2	230.6	196.0	337.4	369.5	217.0	230.8
12	Δ	-39.1	BASE	+709.0	+579.7	+595.8	0	+280.8	+349.7	+130.0

NOTES:

*INCLUDES SEPS

An IUS Galileo, combined spacecraft mission, case 5 in Section 5.3.1.3, utilizing the IUS on a Δ-VEGA trajectory was also analyzed with development of preliminary cost figures. Based on preliminary mission analysis, this option provided, at best, major compromise to the mission which would have to be subjected to detailed review by the scientific community. Further mission analysis, while possible, to identify other mission options would involve much more detailed analysis. In addition to mission deficiencies, the combination of weight and CG location for a Galileo combined spacecraft with kick stage would represent a load to the generic IUS which is greater than design limits. This fact would require, as a minimum, structural modifications to stiffen that upper stage. The implications of such a modification and the cost and schedule consequences as well as risks are not well understood at this time. In summary, while it is apparent that a mission with a combined Galileo spacecraft can be accomplished with upper stage performance characteristics equivalent to an IUS it is not clear that such a mission could be accomplished without major science compromises as well as high cost and schedule risks which would make a single launch in 1985 undesirable. Consequently, as this option provided for extremely high technical risk and a low mission accomplishment reliability factor, the assessment and cost analysis was discontinued.

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SECTION

7.0

SUMMARY

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7.0 SUMMARY

7.1 NASA SUMMARY

7.1.1 INTRODUCTION

As requested by Congress, NASA and DOD have performed a study to determine the nation's upper stage mission requirements and have performed a comprehensive analysis of upper stage options, to define the most appropriate program for meeting the nation's needs.

7.1.2 NASA/COMMERCIAL EARTH-ORBITING REQUIREMENTS

The evolution of commercial spacecraft since the early 1960's has been analyzed. The historical trend showed starting around 1975 spacecraft weight began to stabilize within the performance of the STS. In a number of cases this has required users to limit spacecraft weight and size, increase number of spacecraft, support development of other carrier systems, and develop more complex equipment to fit within weight and size limits.

With an earth orbital transportation system market developing, ESA initiated the Ariane program with several options. Ariane I, II, III and IV will be competitive in performance and cost with the Delta, Atlas Centaur, SSUS-D, SSUS-A and the STS/IUS. Ariane V, which will require a new cryogenic second stage with the Ariane IV, a stage approximately one-half the size of the Saturn S-IVB stage and of similar technology, will be capable of carrying up to 8,500 pounds to geosynchronous orbit. The performance will exceed the current planned STS/IUS performance capability and is expected to be priced so as to be cost competitive. The Intelsat VI spacecraft is being designed to be compatible with Ariane IV. The Centaur STS will exceed the Ariane V performance, 8,500 pounds, by at least 4,500 pounds.

Intelsat has indicated that they see the need for future geosynchronous spacecraft in the 9,000 to 12,000 pound class. Based on past experience this spacecraft development will most certainly take place if firm plans exist for a cryogenic upper stage capable of delivering such spacecraft to geosynchronous orbit. Comsat has also stated that they see future generations of spacecraft to be much heavier than current spacecraft and the industry could very well benefit from a carrier capability such as an integrated Shuttle/Centaur launch system.

Normally, four to five years exist between the initiation of spacecraft design and the flight date. The first commercial use of a high energy upper stage could therefore be between 1986 and 1989, depending on the firmness and maturity of the selected upper stage program. In any case, firm commercial requirements for and use of any new carrier capability will follow by some period of time the development phase of the carrier program.

NASA studies of large space structures show that materials technology makes payloads such as large space platforms and antennas now practical for the late 1980's. Such payloads, because of size and fragility of structure will require upper stage performance with low thrust capability to prevent structural damage from excessive acceleration. This capability has been extensibly demonstrated with RL-10 engine tests. The RL-10 engines are used on the Centaur STS.

In summary of earth orbiting requirements:

1) Spacecraft growth rate has been limited by planned/available carrier capability.

2) ESA has embarked on a vigorous program (the Ariane launch vehicle program) to competitively satisfy user/spacecraft requirements.

3) Spacecraft requirements in the late 1980's and early 1990's will depend on firm upper stage/carrier capability plans existing in the early and mid 1980's.

4) Earth orbital requirements for the late 1980's for a high energy STS upper stage capability, are real. But earth orbital requirements cannot mature, or develop into business ventures because of business risk philosophy, prior to maturity and confirmation of upper stage plans.

7.1.3 NASA PLANETARY REQUIREMENTS

The development of the final mission capabilities and requirements is an iterative process in which launch limitations are accommodated by (1) added trip time to the planets, (2) more launches, i.e., payload split into two or more parts, (3) use of low-energy gravity assisted trajectories based on specific launch opportunities, (4) addition of high energy propulsion systems in the spacecraft itself which complicates design and raises cost, and/or (5) reduction in mission objectives.

Development of a high energy upper stage for the Shuttle will alleviate most of these constraints and significantly improve the cost/scientific return relationship for planetary missions.

The ISPM mission is an approved cooperative mission for 1986 whereby the European Space Agency (ESA) is providing the spacecraft and the U.S. is providing the transportation system. Mission planning and spacecraft system design has proceeded using the Centaur as the most effective upper stage for the program. A change in interface requirements at this time could affect spacecraft cost and established working relationships.

In summary of planetary mission requirements, currently funded missions exist. The first mission, the Galileo scheduled for launch in 1985, with a spacecraft weight of 5,500 pounds and a C_3 of 83, requires the Centaur STS performance capability. For subsequent missions, funded and planned, the requirement exists for similar high energy performance for maximum benefit per mission dollar expenditure, i.e., maximum scientific return per mission cost.

7.1.4 NASA CONCLUSIONS

Assessment of the overall requirement shows that a high energy stage is needed to fulfill projected NASA and commercial needs. Assessment of total program cost to fulfill the mission requirements, as related to possible upper stage program options reveal that the decision should be based on schedule and performance rather than life cycle cost (i.e., cost is not a major discriminator). The long range cost analysis results showed that the variance between options was small and within error inherent in the analysis. The near term cost analysis as related only to planetary missions showed that the cost variations between the baseline and other options with exception of the IOTV options (IOTV cost were much higher) were small. An overall summary by stage is as follows:

The IUS vehicle could satisfy NASA firm earth-orbiting requirements through the 1980's. The IUS is clearly the best option for the TDRS missions for NASA. It does not capture the NASA planetary missions in an efficient manner. It does not meet the anticipated commercial or government performance requirements for the late 1980's or early 1990's.

The Transtage could satisfy the NASA firm earth-orbiting requirements through the 1980's from a performance standpoint, but could not be available in time to support TDRS missions. The Transtage is not efficient for the NASA planetary missions and it does not meet the anticipated commercial or NASA performance requirements for the late 1980's or early 1990's.

The IOTV is the highest cost approach as a new stage would have to be developed. With current requirements, the possible advantage of an IOTV does not appear to justify the additional cost and development time.

The Centaur is the only vehicle able to meet schedule requirements for the current planetary missions. In addition, it could compete on a cost and performance basis for new programs, such as Intelsat VI, beginning in 1986.

The Centaur would meet and exceed the Ariane performance by approximately 4,500 pounds, be available in 1985, and would accommodate the current and envisioned missions through at least the mid-1990's.

SEPS - The SEPS was studied in combination with the IUS, Transtage, and Centaur vehicles. The current IUS combined with SEPS is not as efficient as the Centaur alone for the currently approved planetary missions. The SEPS combined with a high energy upper stage such as the Centaur or IOTV is required for projected NASA missions in the 1990's.

7.2 DOD SUMMARY

7.2.1 INTRODUCTION

Defense missions place a wide range of demands upon all elements of space transportation, including upper stages. These requirements go well beyond the need for a significant amount of energy for payload injection and consider a wide range of operational factors important to maximizing the operational availability of critical defense spacecraft missions. These demands can be expected to increase over time along with demands for increased payload weight lifting capability.

7.2.2 NEAR TERM DEFENSE REQUIREMENTS

As indicated by the assessment in Section 5.0, the Inertial Upper Stage, with modifications, can satisfy all firm defense requirements projected through the 1980's. This is not a surprising result since the IUS was designed specifically to meet those requirements during this period of time. Most operational defense spacecraft programs are undergoing mission block changes concurrent with transition to the Shuttle and the IUS. Consequently, only evolutionary growth can be expected in the systems over the next several years. The operational DOD payload programs also desire to grow to about 5,800 pounds by 1987 and 6,200 pounds by 1988. Some improvements in IUS propulsion will be needed in order to satisfy these evolutionary requirements. Such improvements should be relatively low risk and involve moderate cost to achieve. Should a higher energy upper stage become available before 1990, it is likely that some defense spacecraft programs will take advantage of the enhanced mission capability as opposed to trying for more capability within a constrained payload weight.

7.2.3 LONG TERM DEFENSE REQUIREMENTS

A number of operational defense space programs project significant payload weight increases beginning in 1990 as the new sequence of block change spacecraft become operational. For those programs which do not grow dramatically, the IUS would likely remain the primary launch vehicle. However, for programs whose weight in geosynchronous orbit grows into the 8,000-10,000 lb. range, a significantly more capable upper stage will be required. A new upper stage based either on cryogenic or storable propellants would be suitable for missions in this weight class.

An assessment of the advanced mission concepts for defense satellites, however, shows that beginning in the late 1990's, that significant increases in payload weight will be needed and that a number of different high energy orbits will come into operational use. Since the Shuttle will likely still be the primary vehicle for launching such systems, then the performance limitations will be determined primarily by the upper stage selected. Consequently, the Shuttle throw weight limits--combined with dramatic increase in mission requirements--will ultimately result in the need for the high-efficiency, high-energy levels provided only by a cryogenic liquid propellant stage. Long term defense requirements could be

satisfied by any cryogenic upper stage. The Centaur concept as it is currently being implemented by NASA, would require significant modifications in order to fully satisfy defense requirements. A new stage would be built to these requirements. Further, there is some possibility that a single Shuttle - optimized cryogenic liquid stage (roughly 20 feet in length) could satisfy both defense and NASA planetary mission needs.

Payload weight requirements in the 21st century will require additional propulsion capability such as could be provided by the Solar Electric propulsion System (SEPS), or by alternative payload capability enhancements such as increased Shuttle performance and a new generation of launch vehicles.

7.2.4 DOD CONCLUSIONS

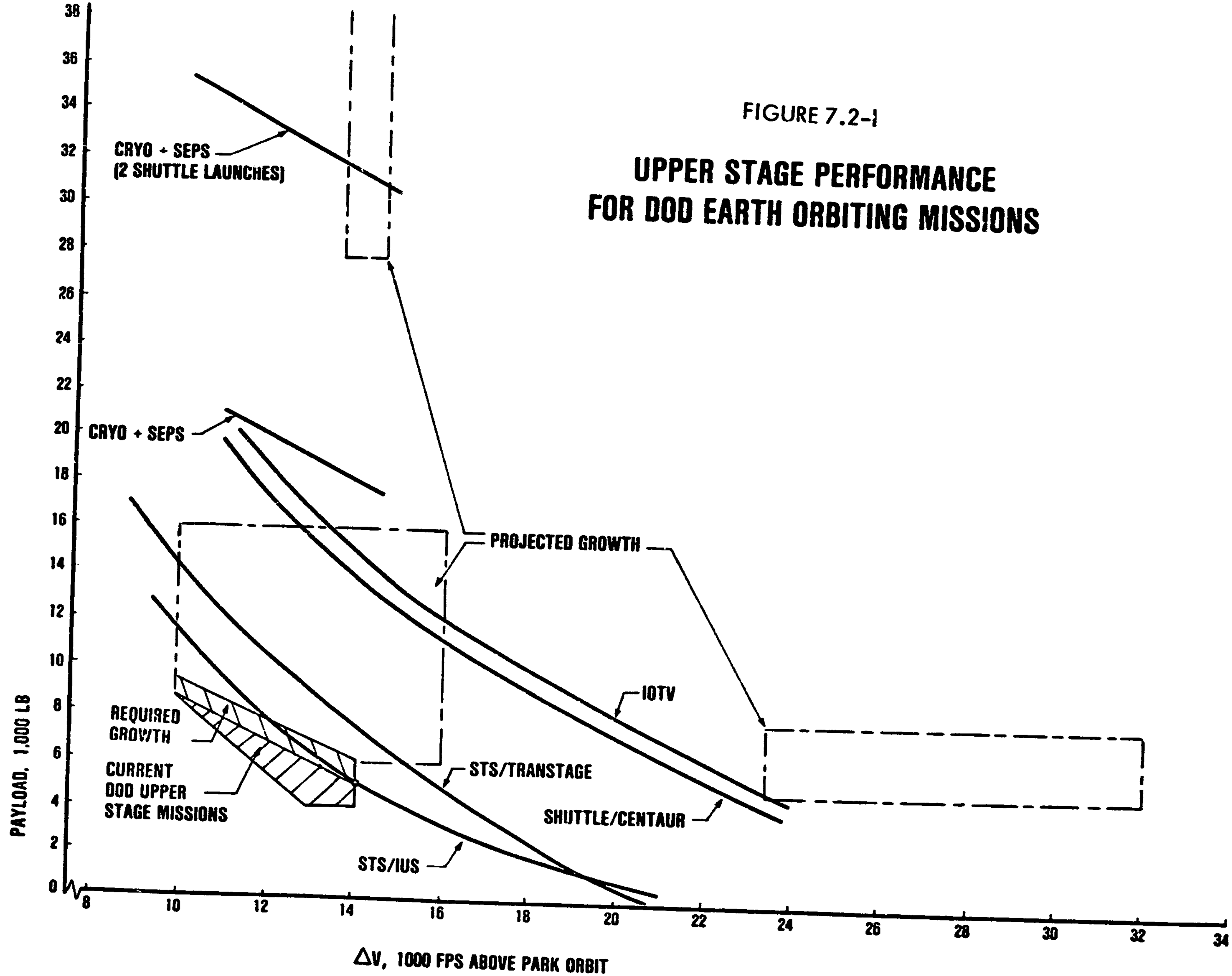
Upper Stage performance requirements (payload weight and injection accuracy) remain the most important discriminator between systems. Figure 7.2-1 illustrates the defense requirements for payload weight in orbit as a function of the incremental velocity required above the Shuttle park orbit; the capability of the various upper stages are then shown relative to those requirements. The firm defense payload requirements are shown by the cross-hatched regions in the lower left of the figure. The potential post-1990 DOD mission requirements are illustrated by the three dashed regions; these regions (marked "projected growth") show significant increases in launch energy. In particular, the dashed region in the upper left of Figure 7.2-1 shows the performance needs for large platforms in high altitude orbits, while the dashed region in the lower right shows the performance needs for "two-way" missions which go to high altitudes and return to the Shuttle.

The Upper Stage performance curves, when overlaid on the mission requirements of Figure 7.2-1, clearly illustrate the appropriate upper stage strategy to satisfy defense needs. The Inertial Upper Stage (IUS) can meet nearly all the firm defense needs, and the IUS can be easily modified to "capture" the small region of missions not within its basic design capability of 5,000 pounds to geosynchronous orbit. The Transtage (or other storable propellant systems) can satisfy all the firm defense needs, but can only capture a small portion of the projected growth. Shuttle payload limits (65,000 pounds) will limit both the IUS and Transtage growth such that these systems can never capture a significant portion of the projected defense needs. The cryogenic propellant stages (Centaur and IOTV) can capture a very large portion of the projected growth, and when combined with the solar electric propulsion system (using two Shuttle flights) could even capture a portion of the large high altitude platform missions.

Consequently, it appears logical to retain the IUS and make necessary incremental performance improvements to meet firm defense needs. There appears to be little benefit to transition to the Transtage, or another storable propellant system, since this approach does not appreciably add to current mission capability and does not capture a significant portion of the projected growth. In terms of overall system capabilities, the Transtage should be considered

FIGURE 7.2-1

UPPER STAGE PERFORMANCE FOR DOD EARTH ORBITING MISSIONS



as a substitute for, rather than a follow on to, the IUS. The logical step for defense missions is to complement the IUS capability with a cryogenic upper stage which will have long term utility.

Figure 7.2-1, however, also illustrates the limitations of upper stages; it will ultimately be necessary to increase the basic Shuttle lift capability (or build larger boosters) to capture all the projected mission growth. Improvements in Shuttle (or booster) lift capability has the effect of moving all the upper stage performance curves up and to the right in Figure 7.2-1 thus increasing the total mission capability.

FIGURE 7.2-2

SUMMARY ASSESSMENT
DOD STS UPPER STAGE REQUIREMENTS SATISFACTION
FOR DOD PAYLOADS

REQUIREMENTS	INERTIAL UPPER STAGE (IUS) DEGREE SATISFY RQMT*		WIDE BODY CENTAUR DEGREE SATISFY RQMT		STS TRANSTAGE DEGREE SATISFY RQMT		IOTV (CRYOGENIC) DEGREE SATISFY RQMT		REMARKS
OPERATIONAL DOD PAYLOADS									
Current Requirements	S		N/A		N/A		N/A		
Requirements thru 1990	S		S/M		S/M		S		
Post 1990 Block Change	S/M \ U		S/M		S/M		S		
POTENTIAL POST-1990 DOD MISSIONS									
As defined	U		S/M		U		S		
Adaptability to Change	U		S/M		U		S		

*Unsatisfactory - U - Does not meet requirement; extremely difficult or impossible to fix. N/A - Not applicable
Satisfactory with Modifications - S/M - Requires Modifications to meet requirements.
Satisfactory - S - Meets requirement completely.

The overall conclusions relative to defense upper stage requirements are presented in Figure 7.3-2, and considers both the performance capabilities presented in Figure 7.2-1 and the operational requirements discussed in this report. These conclusions can be summarized as follows:

IUS, with low risk propulsion upgrades, can satisfy all operational DOD payload program firm and desired capabilities through the 1980's; however, IUS is severely limited in its ability to support operational program block changes in the 1990's, and it probably cannot be adapted to support the potential new missions beginning in the late 1990's.

Transtage (and other storable liquid systems) has capabilities and limitations generally similar to the IUS over the long term. Consequently, it does not appear advantageous to transition defense spacecraft to a storable propellant system.

Centaur provides an adequate growth upper stage for defense missions, although considerable effort (above the planned NASA baseline) would be required to satisfy defense requirements. No firm defense requirement exists before about 1990; however, an early availability would permit enhanced spacecraft mission capability without the constraints of payload weight limits.

A cryogenic propellant IOTV, designed for the full range of defense missions, could be available in sufficient time for DOD needs.

SECTION

8.0

JOINT NASA/DOD

CONCLUSIONS/RECOMMENDATIONS

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8.0 JOINT NASA/DOD CONCLUSIONS/RECOMMENDATIONS

8.1 CONCLUSIONS

The IUS is the only available stage capable of meeting the near term earth-orbiting requirements for DOD and NASA. With modifications, the IUS could satisfy NASA and DOD earth-orbiting missions through the 1980's.

The Transtage (or other storable propellant vehicles) could satisfy near term NASA and DOD earth-orbiting requirements from a performance standpoint, but cannot be available in sufficient time to meet current program schedules. In addition, it is not efficient for NASA planetary missions and falls short of meeting projected long term national performance requirements.

An IOTV since it would be optimally designed to meet national requirements, would be the best upper stage to meet the long term performance and operational needs of both NASA and the DOD. However, this approach is not acceptable since the development time required for such a new stage would not allow the NASA near term requirements to be met. In addition, cost and schedule risks would be considerably higher than for the Wide-body Centaur.

The Centaur is the only vehicle capable of meeting near term NASA planetary requirements, particularly the need for a Galileo combined Orbiter/Probe mission on a direct trajectory to Jupiter in 1985. The Centaur will satisfy the future envisioned and proposed NASA planetary missions through the mid-1990's. The Centaur can also be adapted to meet both current and projected NASA and DOD earth-orbiting requirements and its early availability could provide considerable enhancement to DOD mission capabilities.

Development of a cryogenic upper stage will strengthen the United States leadership role in both hydrogen/oxygen engine technology and in payload lift capability. The long range requirements will drive upper stages toward the very high specific impulse performance provided by hydrogen/oxygen cryogenic stages. Proceeding with a cryogenic upper stage will maintain the small engine cryogenic technology lead, maintain a second domestic source of cryogenic expertise, and strengthen the government's long term competitive opportunities. Proceeding with the wide body Centaur will accomplish these ends and provide a significant and timely jump in upper stage performance. This will allow the United States to compete with the Ariane and also maintain our clear preeminence in the important field of cryogenic engine technology.

8.2 RECOMMENDATIONS

In order to satisfy the national mission requirement/needs of both the DOD and NASA, the Air Force should continue development and production of the IUS and NASA should develop the Centaur.